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Information Gaps and Uncertainties in the IP/RP Compendium Documents and their Impact on Strategic Options

Expert Panel Final Report

A Scoping Study administered by CRESTech/NERAM – Released August 25, 1999

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This Scoping Study followed the guidelines for Expert Panels developed by the Royal Society of Canada. These guidelines specify the formation of three different assemblies to carry out the duties of expert review, research and report preparation, and report review. These assemblies and their members are listed below:

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LIST OF ACRONYMS

AAQC	Ambient Air Quality Criteria (Ontario)
AQMA	Air Quality Management Areas
AQVM	Air Quality Valuation Model (see also HB)
CASAC	Clean Air Scientific Advisory Committee (U.S. EPA)
CD	Compendium Document
CEPA	Canadian Environmental Protection Act
CO	Carbon Monoxide
COI	Cost of Illness
COPD	Chronic Obstructive Pulmonary Disease
EPA	Environmental Protection Agency (United States)
ESOx	Commercial tradename -Control technology developed by EPA
ESONOx	Commercial tradename - Control technology developed by Ontario Power Generation Inc.
ESP	Electrostatic Precipitator
FGD	Flue Gas Desulphurization
H_2S	Hydrogen Sulphide
HB	Hagler Bailly model (see also AQVM)
HEI	Health Effects Institute
HPB	Health Protection Branch (Health Canada)
IP/RP	Inhalable Particulates/Respirable Particulates (syn. $PM_{10}/PM_{2.5}$)
IP/RP OAWG	Inhalable Particulates/Respirable Particulates Options Assessment Working Group
MOE	Ministry of Environment (Ontario)
NAAQS	National Ambient Air Quality Standards (U.S. EPA)
NAPAP	National Acid Precipitation Assessment Program (U.S.)
NAPS	National Air Pollution Surveillance Network (Canada)
NOAEL	No-Observed-Adverse-Effect Level
NO_x	Nitrogen Oxides
NRC	National Research Council (U.S.)
OMA	Ontario Medical Association
PM SAD	Particulate Matter Science Assessment Document
PM/O_3 OAWG	Particulate Matter and Ozone Options Assessment Working Group
PM	Particulate Matter (all sizes)
PM_{10}	Particulate Matter less than or equal to 10 micrometres (μm) in aerodynamic diameter (syn. IP)
$PM_{2.5}$	Particulate Matter less than or equal to 2.5 micrometres (μm) in aerodynamic diameter (syn. RP)
PSRR	Panel Selection and Report Review Committee
PYLL	Potential Years of Life Lost
QALYs	Quality Adjusted Life Years
RR	Relative Risk
RP	Respirable Particulates
SCR	Selective Catalytic Reduction
SNCR	Selective Non-catalytic Reduction
SOD	Strategic Options Document
SO_x	Sulphur Oxides (including SO_2 and sulphates)
SO_2	Sulphur Dioxide

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TAKAHAX	Commercial Tradename – control technology of Nippon Steel (Japan)
TAF	Tracking and Analysis Framework Model
TSP	Total Suspended Particulate (a measure based on sampling with "Hivol" samplers and typically includes particles as large as 40μm in aerodynamic diameter)
TWA	Time-Weighted Average
VOC	Volatile Organic Compounds
VSL	Value of a Statistical Life
WGAQOG	Working Group on Air Quality Objectives and Guidelines
WHO	World Health Organization
WTP	Willingness to Pay

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Executive Summary

Introduction

The purpose of this report is to describe the findings of an Expert Review Panel[1] convened by the PM and Ozone Options Assessment Working Group (PM/0_3 OAWG) (a subcommittee of the Ontario Smog Plan Steering Committee). The Panel was assembled to review two documents recently prepared by the Ontario Ministry of the Environment (MOE):

1. A Compendium of Current Knowledge on Fine Particulate Matter in Ontario

2. Strategic Options to Address the Fine Particulate Issue in Ontario

A Compendium of Current Knowledge on Fine Particulate Matter in Ontario (MOE, December 1998 draft) is intended to provide a detailed review of scientific and technical information on policy and strategic issues, emission inventory development, PM measurements, atmospheric chemistry of fine particle formation, source apportionment, health effects, control technologies, and benefits and costs of PM emission control scenarios in Ontario. The draft Compendium Document (CD) was initially reviewed by the Inhalable and Respirable Particulate Matter Options Assessment Working Group (IP/RP OAWG), now called the PM and Ozone Options Assessment Working Group (PM/O_3 OAWG). A tabular summary of critical comments on the draft CD provided by members of the IP/RP Options Assessment Working, and the corresponding responses by the MOE staff, was included in an appendix to the CD.

Strategic Options to Address the Fine Particulate Issue in Ontario (MOE, December 1998 draft), a companion strategic options document (SOD), aims to provide a framework for developing a strategy to reduce the negative human health and environment impacts from exposure to fine particulate matter in Ontario. The SOD proposes a set of guiding principles for the development of an Ontario IR/RP strategy, followed by a description of respective jurisdictions and mandates for effecting emission reductions from different source types. The SOD describes seven strategic options, and their associated regulatory considerations, for reducing the negative health effects associated with fine particulate matter in Ontario.

The CD is a broad document that attempts to draw together a wide array of information and analysis techniques needed to address this very complex environmental issue. In preparing this document, the Ontario Ministry of the Environment has accomplished a considerable feat, drawing upon the efforts of a number of Ministry scientific, engineering and economic specialists. Indeed the Ministry has demonstrated initiative in addressing the needs of the Smog Plan Steering Committee and the PM/O_3 OAWG by allowing this document to be the subject of a scoping study, and should be commended for this commitment to an open consultation process.

The PM and Ozone Options Assessment Working Group initiated a *Scoping Study on Information Gaps and Uncertainties in the IP/RP Compendium Document and their Impact on Strategic Options*. CRESTech (Centre for Research in Earth and Space Technology) and NERAM (Network for Environmental Risk Assessment and Management) were invited to form a technical secretariat to convene and assist a five member interdisciplinary panel of Ontario academic researchers to provide an independent review of the CD and SOD documents. The Panel included experts in the

[1] The Expert Panel Members are Dr. John Hicks, Ryerson Polytechnic University (Panel Chair); Dr. Jen-Shih Chang, McMaster University; Dr. Donald Cole, McMaster University; Dr. Irene Henriques, York University; Dr. Jochen Rudolph, York University.

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areas of atmospheric sciences, control (and remediation) technologies, health effects, socio-economics (benefit and cost analysis), and risk assessment.

The processes for selection and function of the Panel were based on a formal set of procedures for the conduct of expert panels published by the Royal Society of Canada. One of the most important aspects of the Society's expert panel process is the arm's length relationship with the study sponsors. An independent Panel Review and Selection Committee was appointed by the technical secretariat to select the panel and review the panel report. The final report of the Panel was released to the PM and Ozone Options Assessment Working Group, without any prior review and comment by the sponsors.

The Terms of Reference for the Panel specified by the PM and Ozone Options Assessment Working Group was in the form of four questions. As agreed by all parties during the public component of first meeting of the Panel, the specific objectives of this report are to provide answers to the following four questions:

1. *What are the information gaps in the IP/RP Compendium documents?*

2. *What is the level of uncertainty associated with the information gaps?*

3. *What is the impact of the information gaps/uncertainty on the seven strategic options (describing, where possible, brackets of uncertainty around the options)?*

4. *What program of research should be pursued to close/bridge the gaps and reduce the uncertainties related to the seven strategic options presented in the document (including approximate costs and time frames)?*[2]

INFORMATION GAPS (CHAPTER 1)

Chapter 1 of the Report addresses the issue of identifying important information gaps and scientific uncertainties in the Compendium. This chapter considers both *documentation gaps*, i.e. critical pieces of available information that were not included in the CD, and *scientific uncertainties*, i.e. areas where complete scientific understanding of the IP/RP problem has not yet been established. The chapter is organized according to the major sections of the Compendium, and includes the following topical areas:

- Atmospheric Science
- Control Technology
- Exposure Assessment
- Health Effects Assessment
- Cost-benefit Analysis

[2] The Panel recognized that scoping of approximate costs and time frame for a research program were well beyond the scope of this assignment. This was noted in Appendix B.

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Although these sections may reflect the disciplinary expertise of individual Panel members, all sections of the Report were reviewed and discussed by the Panel as a whole, who maintain joint authorship of the entire Report.

Atmospheric Science

The atmospheric science section aims to provide basic scientific information on the ambient concentrations of PM, their properties, and their sources. This information is essential for the interpretation of health impacts and the development of control strategies.

The CD provides a comprehensive summary of the current state of knowledge as it relates to present atmospheric levels of PM in Ontario, and presents a reasonable section on the chemistry related to the secondary production of PM. The Panel notes that limited spatial and temporal coverage in the available data for PM_{10} and $PM_{2.5}$ leads to questions regarding the representativeness of single site measurements in epidemiological studies, particularly with regard to $PM_{2.5}$ where fewer data are available.

Regarding exposure estimates, the Panel notes that the CD does not acknowledge that ambient concentration is not necessarily a good indicator of human exposure, as most people spend only a small fraction of their time outdoors. Scientific uncertainties remain regarding the link between measured outdoor ambient PM concentrations at given sites and actual breathing zone exposure.

The Panel notes both the importance and the extreme difficulty in defining background PM levels to guide the development of control strategies and assessment of the benefits of controls. There is some ambiguity in the CD and substantial uncertainty regarding background PM levels. The contribution of biogenic VOC emissions to the formation of secondary particles is not considered in the CD. The Panel recognized that background levels (including all sources that cannot be controlled in any jurisdiction or group of jurisdictions) and transboundary PM both be considered in the development of control strategies for Ontario.

The CD provides good coverage of current knowledge of particle composition in Ontario. No information is presented on particle size distributions beyond the distinction between PM_{10} and $PM_{2.5}$. This may be a question of scope of the CD in addition to limited availability of research level information, as chemical composition and size distribution (including composition as a function of particle size) of Ontario PM are only partly known.

The CD correctly indicates that models necessary to undertake source apportionment are in the early stages of development. The understanding of the physical processes of formation, growth and break-up of particles is also highly uncertain. The role of ammonia in particle formation is clearly important. Despite its importance, there is limited knowledge of its emissions or its ambient concentrations.

Concerning the efficiency of reduction strategies, the Panel notes that the assumption in the CD of a linear relationship between emission reductions and exposure or ambient PM levels is likely oversimplistic since the atmospheric residence times of particles of different sizes are different. The Panel identified many areas of scientific uncertainty affecting the assessment of the efficiency of emission reductions including the uncertainty in background PM levels, the impact of particle emission reductions on different particle sizes and the impact of VOC, NO_x and ammonia emission reductions on ambient PM levels.

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Control Technologies

The control technology section of the CD provides descriptive information to evaluate various removal approaches including process modifications, good engineering practices and emission control devices. Overall the Panel found that the available technology is more advanced than what is presented in the CD. Most of the control technology issues for Ontario are related more to barriers to implementation than to lack of effective technologies. Consequently the information gaps identified by the Panel are gaps in documentation rather than lack of knowledge.

The Panel found that the documentation concentrates on the North American experience and does not adequately reflect activity in more aggressive jurisdictions, such as Japan and Germany. Also the Panel noted that in many cases the level of detail presented is insufficient for an adequate comparative analysis of technologies. Recent developments in Ontario and elsewhere involving implementation of SO_x and NO_x removal technologies are not discussed. PM removal technologies are well discussed for limited industrial areas, however no general control devices were reviewed in the document. VOC removal technologies were only addressed in a limited way.

The CD does not indicate that strategic VOC options for low and high VOC concentrations are significantly different. High control efficiencies shown in Table 6.5 only apply to high concentration VOCs. Recent technologies such as biofilters, plasma, UV oxidations, advanced thermal incineration and catalytic oxidation techniques are not discussed. The Panel also noted that there is no review of integrated control technologies for PM, SO_x, NO_x and VOCs.

The CD discusses process modifications and good engineering practices as control technologies but fails to provide a comprehensive discussion of the technological and theoretical limits associated with these options. The Panel notes that technologies for PM_{10} to $PM_{2.5}$ removal do exist. The major source of uncertainty is with regard to the cost of integrated control systems.

Exposure Assessment

There is no simple 'particle metric' to relate ambient atmospheric particulates to human health. At this time, guidelines/standards generally use measures of PM_{10} (the most widely used metric), and $PM_{2.5}$ (less frequently applied). However, this preference is predominantly attributable to the availability or absence of ambient measurements, and is not supported by a mechanistic understanding of the health effects caused by particulate matter.

PM is a complex mixture of particles of varying size and chemical speciation. While ambient exposure concentrations to PM_{10} and $PM_{2.5}$ are often highly correlated, the Panel concluded that the CD has appropriately identified the relevant evidence to suggest that $PM_{2.5}$ may be more closely linked with health effects. Further research is needed to confirm the conclusion reported in the CD that for PM-associated health effects *"over 90% of premature mortalities and hospital admissions are due to $PM_{2.5}$ based on preliminary analysis of data from a few Ontario urban sites"*. The possibility should be considered that the strong association of $PM_{2.5}$ with adverse health effects may be overstated, as $PM_{2.5}$ could act as a surrogate measure for the toxic sub-fraction(s) of airborne particles, such as sulphates or metals. It does not follow that a reduced concentration of an exposure surrogate will necessarily reduce mortality.

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Health Effects Assessment

The Panel noted that the CD provides a thorough review of the available evidence to answer the question of whether there is a causal link between PM exposure and cardiopulmonary mortality and morbidity. However, most of this discussion is based exclusively on the summary chapter of the recent Science Assessment Document on Particulate Matter (PM SAD) produced by the Federal-Provincial Working Group on Air Quality Objectives and Guidelines (WGOQOG). The Panel noted that it is unclear whether findings and conclusions presented in the CD reflect further examination of the SAD by the CD authours. The CD also omitted a discussion of criteria for deriving the Reference Level (RL) of 25 ug/m^3 PM_{10} which is presented in Chapter 14 of the SAD. This discussion would provide greater clarity to the use of Reference Levels in the section on Estimate of Health Impacts.

The CD appropriately reviews the results of epidemiological studies using a weight-of-evidence framework according to four causality criteria (1) *consistency* of the statistical association (2) *strength* of the association (3) *specificity* of the association and (4) *coherence* of the association. In support of consistency of the statistical association, the CD notes that two large cohort studies – the Harvard Six Cities Study and the American Cancer Society Study support the findings of previous time-series and cross-section studies which show an association between PM exposure and excess cardiopulmonary mortality and morbidity. The CD does not discuss the California Seventh Day Adventist Study which did not detect a statistically significant elevation of cardiopulmonary mortality. In addition, possible sources of bias and confounding in large-scale studies, such as weather factors or gaseous co-pollutants (especially ozone) are not adequately discussed. The Health Effects Institute re-analysis of the Harvard Six Cities Study that addresses the issue of potential confounders should be included in the CD.

To address specificity of the association, the CD discusses a variety of reported health effects endpoints, and their common linkage to cardiopulmonary disease is explained. The Panel cautioned, however, that the specificity of health effect may be overstated in the CD, as acute and chronic mortality effects of PM may be the result of distinct disease processes. The Panel called for more extensive examination of possible toxicological mechanisms of acute and chronic PM toxicity.

Regarding coherence of the association, the CD is not clear about the implications of attempting to combine the findings of time series studies and cohort studies. While both types of studies indicate excess mortality risks, the causal linkages underlying the two sets of studies is not clearly explained, mainly because the basic toxicological mechanisms behind acute and chronic health effects are not clear. The presentation in the CD of "pyramid of effects" relating PM-associated pulmonary morbidity (e.g. pulmonary symptoms, asthma, cardiopulmonary hospitalizations) to PM associated mortality is a weak argument for coherence as it reflects risk estimates from a predictive dose-response model rather than empirical findings from epidemiological studies.

One of the critical issues in understanding the public health significance of PM exposure is the extent to which it reduces life expectancy or quality of life. The CD fails to provide an adequate discussion of the "harvesting effect", that is, the possibility that PM only advances death by a few days among chronically ill and elderly persons with end-stage cardiopulmonary disease. While the extent of the harvesting effect is currently under scientific investigation, the Panel calls for a more extensive discussion of this question in the CD given its importance in policy formation.

The Panel concluded that the most serious weakness in the Health Effects section is the lack of information required to characterize the dose-response relationship between ambient

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concentrations of PM_{10} or $PM_{2.5}$ and specific health effects. The derivation of the various mortality and morbidity risk coefficients, while reasonably well-documented in the AQVM Methodology report as referenced in the CD, is not explicitly discussed within the CD itself. The Panel questioned the validity of the methodology used in the Hagler-Bailly (HB) model to derive mortality risk coefficients to estimate annual PM associate mortality in Ontario. Three alternative values for the mortality risk coefficients are derived. These values are labeled high, midpoint and low as if they were meant to account for parameter uncertainty. The high and medium mortality coefficient values are derived from times series PM studies and the low value is apparently derived from chronic cohort PM studies. The Panel questioned the validity of mixing parameter uncertainty and model uncertainty in a single set of mortality risk coefficients.

The CD correctly reports that there is a roughly linear dose-response relationship in the observable range of PM concentrations, with no observable threshold at any concentration level. But the CD fails to explain that the absence of a detectable dose-response threshold does not disprove the possibility of a threshold at low levels of exposure. The mortality risk coefficient for exposures below 20-25 ug/m^3 (24 hour) PM_{10} concentration is based exclusively on statistical extrapolation of the modelled dose-response curve, rather than on empirical findings. While this technique is often deemed acceptable in quantitative risk estimation when it is based on well-founded toxicological mechanisms in animal or human studies, the evidence of a toxicological mechanism is lacking for PM. The Panel further noted that exposure misclassification errors in time series studies obscures the shape of the dose-response curve in the exposure region below about 25 ug/m^3 PM_{10}. The Panel concluded that the acceptance of a linear non-threshold dose-response model for particulates could be viewed as a regulatory 'default assumption' based on a serious knowledge gap, but not as a substantiated scientific finding.

Cost-Benefit Assessment

The Cost-Benefit Analysis section of the CD describes the methodological approaches used in estimating two quantities:

- Health benefits - annual monetized benefits of morbidity and mortality reduction in the Ontario population, resulting from various projected levels of reduced ambient concentrations of PM_{10}, and

- Cost of control - cost of control incurred by Ontario industries in achieving targeted reductions in ambient PM_{10} levels, based on the estimated reduction in industrial emissions required to achieve a specified ambient PM_{10} level.

The Panel was critical of the lack of documentation about the methodology used to estimate the projected health benefits for Ontario from reduced exposure to PM. While precise estimates of annual mortality and respiratory morbidity are presented in the CD as a summary table, there is no supporting documentation of the data sources or means of derivation of the mortality and morbidity risk coefficients, which themselves are not presented. While the CD does provide a description of the approach used by the Hagler-Bailly (HB) model to estimate the predicted annual mortality and respiratory morbidity association with PM_{10} exposure in Ontario, the model is not subject to close examination in the CD concerning its model structure, computation methods, data inputs, underlying assumptions and various strengths and weaknesses. Better documentation related to how the HB model deals with uncertainty in model input values -- such as mortality risk coefficients, willingness to pay (WTP) valuations on mortality, etc. -- is essential, given the reliance on the HB model outputs for the analysis of benefits and costs associated with reduction scenarios.

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The cost-benefit analysis section of the CD suffers from the weaknesses described previously regarding the lack of documentation associated with the use of proprietary models (i.e. Hagler-Bailly model) to estimate health effects and health benefits. The Panel notes again that the HB model is flawed by its over-reliance on a linear nonthreshold dose-response function for all estimates of the projected health benefits from ambient PM_{10} reductions. The Panel noted that the CD does not adequately cite studies to support the assertion that "research has revealed that many contaminants, including PM_{10} and $PM_{2.5}$ exhibit no ambient concentration thresholds (above zero). The Panel recommends that the benefit analysis should explore the sensitivity of health benefits to the inclusion of a possible dose-response threshold for PM_{10} health effects.

The Panel concluded that the exclusive reliance on the modelling assumption that a linear non-threshold dose-response exists at all levels above zero exposure in the HB model health effects estimation is not appropriate, and may grossly inflate the estimated health benefits of PM_{10} reductions for exposures below approximately 25 ug/m^3. *The* Panel considers the potential impact of this omission to be critical considering the majority of person-days of PM_{10} exposure in Ontario are well below the PM SAD Reference Level of 25 ug/m^3.

The Panel noted that the CD fails to consider the potential health benefits associated with emission reductions in Ontario to populations downwind of Ontario, specifically Eastern Canada and the Eastern United States.

The Panel recognized that many costs and benefits, particularly the value of human life, are difficult to evaluate in monetary terms and their evaluation is a subject of active discussion among economists. The greatest uncertainties in valuation of health benefits centre on the methods for deriving a valid set of monetized values for PM-associated mortality and morbidity. The benefits analysis in the CD also omits aquatic and soil effects benefits, visibility effects benefits, the effects benefits to material and cultural resources, nonuse of ecosystem health, recreational forests, agricultural and commercial forestry benefits.

The Panel recommends that the benefits analysis could be improved, by making more transparent the model's underlying assumptions, computational formulas, sources of uncertainties, and by conducting appropriate sensitivity analysis on WTP measures and other uncertain values.

The CD presents a cost analysis of particulate matter emission control scenarios in Ontario using 1990 data. These estimates are to be updated using 1995 data and a proprietary tool called AERCO$T™ developed under contract by SENES for Environment Canada (see SENES (1995) and SENES (1996)). The estimates in the CD report, however, used a previous version (SENES (1992) of the AERCO$T™ model. The functionality, validation or underlying assumptions of the AERCO$T™ model are not documented in the CD, as AERCO$T™ is a proprietary model. This lack of transparency regarding the underlying features of the AERCO$T™ model is viewed by the Panel as a serious weakness in the CD. While SENES has ground-truthed the cost estimating algorithms incorporated within the AERCO$T™ model, by obtaining actual costs for existing facilities from those companies that were willing to participate, the Panel questions the rigor of this approach to model validation and recommends an independent validation of the model.

While the Panel notes that all costs in the CD relate to implementation of technology controls, the costs associated with monitoring and/or enforcement to ensure that emission objectives/target are reached are not included in the analysis. The Panel recommends that the CD broaden the consideration of costs beyond the cost of implementation of controls to inform on how companies

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assess costs and benefits associated with pollution control technologies. A list of possible implementation strategies (emissions trading, pollution taxes, voluntary controls and regulatory controls) and their associated costs/benefits would strengthen the CD.

The Panel notes that the abatement cost functions fail to consider that emissions reductions for Ontario industries can only accomplish a partial reduction in ambient PM in Ontario as a significant proportion of PM and PM precursor air pollution in Ontario is generated from the Central United States. Further, the positive impact of emission control programs for other air pollutants (i.e. removal of sulphur in gasoline) in reducing emissions of PM precursor pollutants are not factored into the cost analysis.

The Hagler-Bailly and AERCO$T™ models do not allow for an integrated assessment of costs and benefits of emission reductions, since they do not explore costs and benefits under a consistent set of assumptions. An important aspect of understanding cost-benefit analysis is to establish the time horizon of the various costs and benefits. The present value of the net benefits of a project are critically dependent upon the choice of discount rates. The Panel calls for a sensitivity analysis of the discount rate.

The HB model and AERCO$T™ model both depend on the "proportional rollback' scenario for PM emissions reduction, which assumes that all industrial firms, sources and sectors in Ontario will be required to reduce PM emissions by an equivalent proportion. An alternative scenario, the 'peak shaving' scenario is briefly discussed in the CD but is not analyzed qualitatively using the HB or AERCO$T™ models. The peak shaving strategy is based on identifying and mitigating those emission sources, which have the greatest impact on daily or weekly ambient PM excursions. This omission is an important weakness, considering that the monetizing of health benefits in the HB model is predominantly influenced by mortality effects from acute PM exposure. The Panel notes that consideration of the peak shaving scenario would inform decision-making with respect to the costs of control for PM emissions in urban Air Quality Management areas (AQMA) in Ontario, which was identified as one of seven possible Strategic Options to address the fine particulate issue in Ontario.

LEVELS AND SOURCES OF UNCERTAINTY (CHAPTER 2)

The Panel considers that a comprehensive and systematic quantification of the impact of gaps and uncertainties on strategic options is not feasible at the present state of knowledge. Consequently, the Panel has elected to produce a summary framework based on a scheme for characterizing the *level of uncertainty* in a semi-quantitative manner, first proposed by Wynne in 1992:

- *risk*, which occurs when the degree of scientific understanding and empirical information is sufficiently high to permit the accurate prediction of adverse environmental consequences with a high degree of confidence;

- *uncertainty*, which occurs when partial scientific information is available to understand and predict a risk, but the information is incomplete or contradictory;

- *ignorance*, reflecting a situation where there is fragmentary information about a risk, and little or no understanding of the scientific principles that determine risk; and

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- *indeterminacy*, where it is basically impossible to address a problem scientifically, either because the problem is too complex a task for current investigational techniques, or because the question is not accessible to scientific enquiry.

The Panel has also adopted a second scheme for characterizing the *sources of uncertainty*, employing an uncertainty framework developed by Finkel (1990). This approach divides uncertainty into several major categories:

- *parameter uncertainty* is attributable to statistical uncertainty in the model parameters due to measurement error and sampling error, and from systematic errors arising from biased sampling or flawed experimental design;

- *model uncertainty* reflects the limited ability of mathematical models to accurately represent the real world;

- *decision-rule* uncertainty takes the form of imprecise or inappropriate operational definitions for desired outcome criteria, value parameters, and decision variables; and

- *integration uncertainty* reflects the problem of combining disparate scientific and economic models, commonly based on fundamental assumptions and formulas that are incompatible.

As a final step in characterizing the major levels and sources of uncertainty regarding the PM problem, the Panel members have devised a summary table which delineates: (1) the major information gaps; (2) the level of uncertainty of these gaps; and (3) the sources of uncertainty. This table is not meant to be strictly analytical, but rather reflects the expert judgement of the individual Panel members concerning the uncertainty issues related to specific information gaps.

STRATEGIC OPTIONS (CHAPTER 3)

The Strategic Options document (SOD) provides a set of seven Strategic Options for controlling ambient particulate matter pollution in Ontario. The options are presented both as a descriptive listing of options and as an annotated summary table. The Panel members focused on discussion of the information provided in the summary Table 1 (see Appendix A). The Panel noted the following general comments on the SOD:

- The document lacks a clear rationale, framework or criteria to indicate the process by which the seven Strategic Options were derived. Although the document describes "guiding principles for developing an IP/RP strategy" and a list of 6 "additional considerations", there is no apparent link between this material and the strategic options. As a result, the Panel had difficulty in assessing the options in a consistent and objective manner.

- The seven Strategic Options do not constitute a comprehensive and mutually exclusive set of options. The various control measures include several distinct types of control criteria including, revised AAQC levels for ambient PM, emission control targets for PM sources and gaseous precursors, and various AAQC levels for Air Quality Management areas (AQMA). Those listed could be considered as prototypes of many other possible strategic options.

- A comprehensive and systematic quantification of the impact of gaps and uncertainties on strategic options is not feasible given the current state of knowledge. However, the Panel

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agreed with the view expressed in the SOD that gaps in the science should not be used as a reason for delaying actions to address the issue.

The Panel proceeded by first broadly analyzing the seven Strategic Options by characterizing the options according to five major criteria: ambient air concentration level, particle size, form of attainment, geographic unit of attainment, implementation time frame and emissions reductions strategy.

The second phase of the Panel's analyses of the Strategic Options focused on characterizing the options into viable and non-viable options and commenting on how the gaps and uncertainties in scientific knowledge impact on the strategic options.

The Panel characterized SOD Options 4, 5 and 7 as non-viable in light of the information gaps encountered in the CD. The CD does not provide community-specific source receptor information or cost-benefit information at a community level for consideration of the Air Quality Management Area approach (Options 4 and 5). Harmonization with the U.S. (Option 7) is considered non-viable as the current U.S. EPA (150 ug/m^3 PM_{10}) standard is considerably higher that the current Ontario interim standard (50 ug/m^3 PM_{10}) and is not considered protective of human health given the no threshold assumption. The costs and health benefit analyses in the CD provide information for further consideration of various approaches for setting policy based on AAQC levels (Options 1, 2, 3, 6). Uncertainties affecting these estimates are associated with the exclusive adherence to linear proportion rollback approach and linear nonthreshold dose-response models, and the questionable methodology for deriving cost estimates of emission controls.

The lack of $PM_{2.5}$ monitoring capability and the lack of information on the relationship between emissions and ambient concentrations will pose a challenge in the setting of target levels and target dates in Option 2, 3 and 6. Uncertainties in the importance of chemical composition and size distribution on health effects make it difficult to provide a clear rationale for prioritizing PM_{10} or $PM_{2.5}$ in a strategy for managing fine particulate matter. Uncertainties regarding the costs of control for $PM_{2.5}$ pose further limitations in including cost-effectiveness considerations in decision-making for control strategies.

RESEARCH PROGRAM (CHAPTER 4)

The Panel has listed a number of research needs that are designed to remove the significant information gaps and improve Ontario's capability to develop a strong and balanced environmental policy. The range of research needs extends from the development of routine IP/RP monitoring network, to the development of broad risk-benefit model for air quality regulatory applications.

Monitoring and Measurements: There is a need for an Ontario network of PM_{10} and $PM_{2.5}$ monitors and a corresponding analytical capability that will allow the collection and analysis of air quality information. Health effects monitoring (e.g. hospital admissions for respiratory ailments, physician visits) is recommended to assist epidemiological studies.

Modelling: The Panel recommends research activities that contribute to our understanding of the Ontario airshed including the *transboundary*, *natural background*, and *secondary particulate* components of the provincial particulate budget. In addition, exposure modelling for a number of average and highly susceptible Ontario sub-populations is needed, using both ambient and personal exposure models. An Ontario-based risk-benefit model is needed to evaluate the health and economic impacts of particulate matter and other air pollutants.

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Mechanistic: Further research is needed to identify the mechanisms of secondary particulate formation in the atmosphere. In addition, mechanistic research on deposition and uptake of inhaled particulate and other co-pollutants is recommended.

Intervention/Regulatory: The Panel believes there is a need for research into the effectiveness of different interventions and regulations for controlling the sources or effects of air pollutants.

The Panel did not prioritize the research needs listed above and agreed that it was beyond the scope of this study to determine approximate costs and the time frame for a research program.

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Introduction

Two documents were recently prepared by Ontario Ministry of Environment (MOE) for the ONTARIO SMOG PLAN STEERING COMMITTEE, providing a compilation of available scientific and technical information as a resource for public consultation in developing an Ontario IP/RP Strategy:

1. *A Compendium of Current Knowledge on Fine Particulate Matter in Ontario*
2. *Strategic Options to Address the Fine Particulate Issue in Ontario*

Inhalable particulate matter (IP; PM_{10}) is the portion of the total air particulate matter 10 micrometres (μm) or less in diameter. Most particles with diameters greater than 10 μm are caught in the nose and throat, not reaching the lungs. *Respirable particulate* matter (RP; $PM_{2.5}$; the fine fraction of PM_{10}), is that portion of the total air particulate matter 2.5 μm or less in diameter. Both the inhalable and respirable particulate fractions can penetrate deeply into the lungs, and are therefore considered as a potential hazard to human health.

The *Compendium of Current Knowledge on Fine Particulate Matter in Ontario* (MOE, December 1998 draft) provides detailed scientific and technical information on policy and strategic issues, emission inventory development, particulate matter measurements, atmospheric chemistry of fine particle formation, source apportionment, health effects, control technologies, and benefits and costs of PM emission control scenarios in Ontario. The Compendium was reviewed by the INHALABLE AND RESPIRABLE PARTICULATE MATTER OPTIONS ASSESSMENT WORKING GROUP (IP/RP OAWG), now referred to as the PM AND OZONE OPTIONS ASSESSMENT WORKING GROUP (PM/O_3 OAWG). Comments on the draft document provided by members of the IP/RP OAWG, and responses by the document authours, are documented in an appendix to the Compendium.

The companion document *Strategic Options to Address the Fine Particulate Issue in Ontario* (MOE, December 1998 draft) aims to provide a framework to develop a strategy to reduce the potential negative human health and environmental impacts from exposure to fine particulate matter in Ontario. Guiding principles are proposed for the development of an Ontario IP/RP strategy, followed by a description of respective jurisdictions/mandates for effecting emission reductions from different source types. Seven strategic options and associated considerations are described for reducing the potential negative effects associated with fine particulate matter in Ontario.

The IP/RP OAWG initiated a *Scoping Study on Information Gaps and Uncertainties in the IP/RP Compendium Document and their Impact on Strategic Options*. CRESTech (Centre for Research in Earth and Space Technology), in partnership with NERAM (Network for Environmental Risk Assessment and Management) were invited to form a technical secretariat and to convene and assist a five member multidisciplinary Expert Review Panel of Ontario academic researchers to provide an independent review of the above documents.

The Panel was selected and operated, as closely as possible, under the procedural guidelines for expert panels as set out by the Royal Society of Canada. Sponsors for the study were solicited from the SMOG PLAN STEERING COMMITTEE and the IP/RP OAWG. Support funding, totalling $38,500, was provided from a number of sponsor sources: Alliance of Manufacturers & Exporters, Canadian Chemical Producers Association (CCPA), Ontario Ministry of Environment (MOE), Regional Municipality of Hamilton-Wentworth, Canadian Petroleum Products Institute (CPPI), Ontario Power Generation (OPG), John Deere Welland Works, Canadian Steel Producers

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Association (CSPA), Canadian Portland Cement Association (CPCA), Lambton Industrial Society (LIS), Ontario Natural Gas Association (ONGA), and CRESTech.

One of the most important aspects of the Royal Society's expert panel process is the arm's length relationship established between the study sponsors and the panel. The panel is completely independent of the sponsors; all sponsor funds are received in advance of the final report and the funding is used solely to cover the costs of the study. The panelists receive only a small honorarium as a token of appreciation, not compensation for services. In this study, the SPONSORS COMMITTEE was defined as the entire IP/RP OAWG (now the PM/O_3 OAWG).

An independent PANEL SELECTION AND REPORT REVIEW (PSRR) COMMITTEE was created by the technical secretariat to select the panel members and conduct a peer review of the Panel's final report. This committee consisted of: Dr. Geoff Harris (Centre for Atmospheric Chemistry, York University), Marjorie Shepherd (Atmospheric Environment Service, Environment Canada) and Dr. Robert F. Willes (Cantox Environmental Inc.). The technical secretariat developed a long list of potential panelists, contacted individuals to determine their willingness to serve on the panel and prepared a nomination report for the PSRR Committee. This nomination report included the curricula vitae, conflict of interest and points of view forms for candidate panelists.

Based on this information, the PSRR Committee met on March 31, 1999 and selected five panelists based on the following criteria: composition (appropriate mix of experts and expertise in more than one area), balance (differing points of view), conflict of interest, and reasonable travel costs. The committee also identified a potential chairperson for the panel. As defined in the terms of reference for this study, five areas of expertise were required: atmospheric sciences (emission inventories, PM measurements, atmospheric chemistry and physics, source apportionment, data analysis and modelling), control (and remediation) technologies, health effects (and biostatistics), socio-economics (benefit and cost analysis), and risk assessment (including exposure assessment). The PSRR Committee made the following recommendations:

(a) Given a lack of expertise among the candidates in the area of emission inventories and their application in regional air quality and economic models, it was recommended that the panel request the secretariat provide support in this area. The response to this recommendation was to include Dr. Don Hastie (York University) as part of the technical secretariat.

(b) The Panel requested that the secretariat provide support for additional expertise in the area of dose-response modelling and risk characterization, particularly when interpreting the analysis of epidemiological information on potential health outcomes. The response to this recommendation was to include Dr. Stephen McColl (University of Waterloo) as part of the technical secretariat.

(c) Five scientists with appropriate expertise either singly or in combination, in the areas identified for Panel membership, were selected as follows:

Atmospheric Studies:	Dr. Jochen Rudolph, York University
Health Effects:	Dr. Donald Cole, McMaster University
Socio-Economics:	Dr. Irene Henriques, York University
Control Technologies:	Dr. Jen-Shih Chang, McMaster University
Risk Assessment:	Dr. John Hicks, Ryerson Polytechic University – Panel Chair

The Panel started work on April 20, 1999 at Meeting # 1, which was held to clarify the terms of reference with the study sponsors (meeting in open session) and to develop a work plan (meeting

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in executive session). The Panel held an open consultation with the project stakeholders, defined as the members of the PM/O_3 OAWG, to identify salient issues and to clarify the review process with these stakeholders. Shortly after this meeting, the Panel Chair (Dr. Hicks) mailed a letter to all members of this stakeholder group to suggest how stakeholders who wished to provide comments on the review process could contact the Panel (see Appendix B). No written responses were received from any of the stakeholders concerning the review process. The Panel's deliberations continued via e-mail, conference calls and two informal meetings (May 5 and 19, 1999). The final formal meeting occurred on June 1, 1999 and there was an additional conference call on June 15, 1999.

It was the responsibility of the PSRR Committee to conduct an internal review of the Panel's final report -- this review was intended only to ensure the textual clarity of the report and did not materially alter the Panel's findings. The peer review by the PSRR Committee occurred during the week of July 19th and the final report of the Panel was released to the PM/O_3 OAWG on July 27th, 1999 without any prior review or comment by the study sponsors or the PM/O_3 OAWG. The report is to be published by the technical secretariat within 30 days of this date without revision, as agreed with the study sponsors at Meeting #1. The purpose of this delay in publication is to give the sponsors an opportunity to discuss the report internally and consider the findings.

The objectives of the IP/RP Scoping Study undertaken by the Expert Panel were as follows:

1. *To conduct a review of the IP/RP Compendium document and the Strategic Options document;*
2. *To identify the information gaps;*
3. *To determine the level of uncertainty associated with the information gaps;*
4. *To assess the impact of the information gaps/uncertainty on the seven strategic options (describing, where possible, brackets of uncertainty around the options); and*
5. *To outline the path forward by defining a research program to close/bridge the gaps and reduce the uncertainties related to the seven strategic options presented in the document . (including approximate costs and time frames).*

As agreed by all parties during the public component of first meeting of the Panel, the specific objectives of this report are to provide answers to the following four questions:

1. *What are the information gaps in the IP/RP Compendium documents?*
2. *What is the level of uncertainty associated with the information gaps?*
3. *What is the impact of the information gaps/uncertainty on the seven strategic options (describing, where possible, brackets of uncertainty around the options)?*
4. *What program of research should be pursued to close/bridge the gaps and reduce the uncertainties related to the seven strategic options presented in the document?*

The findings and recommendations made in response to these questions, as presented in the final report, are entirely those of the Expert Panel, and were derived by reaching consensus among Panel members wherever possible. For important issues where reasonable consensus could not be achieved, the minority viewpoint has been summarized in a footnote within the appropriate section of the final report.

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Chapter 1

Information Gaps

The purpose of Chapter 1 is to identify important information gaps and scientific uncertainties in the Compendium Document. This chapter considers both *documentation gaps*, i.e. critical pieces of available information that were not included in the CD, and *scientific uncertainties*, i.e. areas where complete scientific understanding of the IP/RP problem has not yet been established. The chapter is organized according to the major sections of the Compendium, and includes the following topical areas:

- Atmospheric Science
- Control Technology
- Exposure Assessment
- Health Effects
- Cost-Benefit Analysis

I: Atmospheric Science

Major questions

Within the Compendium Document, the section on Atmospheric Science aims to provide basic scientific information on the ambient concentrations of PM, their properties and their sources. This information/knowledge is essential for the interpretation of health impacts and the development of control strategies. There are many areas where uncertainties impact on the suitability or usefulness of Ambient Air Quality Criterion (AAQC) for particulate matter (PM). The Panel focused on the uncertainties that, according to present understanding, have the largest impact on various options. These knowledge gaps and uncertainties in this area can be addressed through the following questions:

1. *To what extent is there sufficient knowledge of the spatial and temporal variation of the concentrations of PM_{10} and $PM_{2.5}$ for use in health studies and in the development of control strategies?*

2. *To what extent can human exposures be determined from the existing ambient concentration data?*

3. *Are background levels of PM sufficiently well defined for meaningful interpretation of other data?*

4. *If health studies are to focus on the size distributions and chemical composition and PM, are these sufficiently well understood for these applications?*

5. *Can ambient PM be apportioned to various sources?*

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6. *Is the relationship between emissions and sources sufficiently well understood to relate changes in emissions to changes in ambient concentration?*

1. Present atmospheric levels of PM

A. Document Issues

The Compendium Document provides a comprehensive summary of the current state of knowledge of PM as it relates to Ontario. Existing data from Ontario, across Canada, and in the United States is presented. There is also a reasonable section on the chemistry related to the secondary production of PM.

B. Scientific Uncertainties

Epidemiological studies have examined the association between mortality and measures of ambient PM mass concentration such as PM_{10} (usually $\mu g\ m^{-3}$). In early studies, Total Suspended Particulate (TSP) was also employed as a measure of air quality. More recently there has been an emphasis on measured $PM_{2.5}$ concentrations in epidemiological studies. However there is only limited spatial and temporal coverage in the available data for PM_{10} and $PM_{2.5}$. This leads to questions as to the representativeness of single site measurements. The problem is more acute with $PM_{2.5}$ as there are fewer data available.

2. Exposure Estimates

A. Document Issues

People in Ontario spend only a small fraction of their time outdoors. Therefore ambient measurements are not necessarily a good indicator of human exposure to PM. The Compendium Document does not address this important issue.

B. Scientific Uncertainties

The questions regarding the atmospheric levels can be directly applied to exposure estimates. Any error or lack of knowledge in the ambient concentrations will be directly transferred to exposure estimates.

The relationship between measured outdoor ambient PM concentration at given sites and actual breathing zone exposure is not well understood. This is one of the research priorities in the NRC report (National Research Council, 1998). Specifically, deriving exposure from ambient measurements requires a very detailed knowledge of temporal and spatial variability that currently is not available.

3. Background levels

A. Document Issues

The definitions of the natural background PM level (in the absence of any anthropogenic input) and the ambient level PM (in the absence of Ontario anthropogenic input) are of critical

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importance in both the development of control strategies and in assessing the benefits of such controls. Unless these levels are well known, the air quality impact of an emission control strategy cannot be properly determined, nor can the costs and benefits of meeting an ambient air quality standard.

Within the Compendium Document there is some ambiguity and substantial uncertainty that result from questions associated with "background" PM levels. The natural PM background levels are only poorly defined. A value of 5 $\mu g/m^3$ is often quoted but it must be noted that this number is very location specific. Some measurements, for example, from marine areas report aerosol loading as high as 10 $\mu g/m^3$.

The contribution of biogenic volatile organic compound (VOCs) emissions to the formation of secondary particles is not considered.

B. Scientific Uncertainties

For purposes of control and health assessments following controls, the most relevant background value is one that would include all sources that cannot be controlled. The reasons for this inability to control should be technical, for example it may be impossible to control emissions from natural sources or some forms of mechanical wear. For PM this level is not only extremely difficult to assess but will also have a high temporal and spatial variability. It requires an understanding of all sources of ambient PM, and the ability to accurately apportion those sources.

Ontario does not have an isolated airshed, and so its air quality problems cannot be considered in isolation. An understanding of the transport of PM resulting from emissions in other provinces or the U.S. into Ontario is critical. From the presented results and other experiences with "across-border" transport of pollutants it can be estimated that about 50% of the PM_{10} and $PM_{2.5}$ are not from sources in Ontario (Ontario Ministry of Environment, 1999). If transported PM is not considered, this greatly increases the extent of reduction needed to achieve an ambient air quality standard in Ontario. If it is neglected altogether it will reduce the actual impact of any given reduction limited to Ontario.

Biogenic VOC emissions (primarily terpenes) are known to undergo atmospheric reactions which produce PM. The neglect of this secondary PM formation from natural hydrocarbon emissions will have a similar impact to the neglect of transported PM. In summer, when biogenic emissions are significant, this will result in a systematic underestimate of background levels and overestimate of the impact of any reductions in anthropogenic emissions.

4.Knowledge of particle composition and size distributions

A. Document Issues

The Compendium Document has good coverage of what is known about particle composition in Ontario. It shows there is quite detailed knowledge of inorganic and crustal components, but that the carbon and organic components are less clearly understood. There is no information on particle size distributions. The only size information is the distinction between PM_{10} and $PM_{2.5}$. The Panel notes this is really a question of scope of the Document, but does point out that limited research level information (as opposed to monitoring information) on size distributions is available.

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B. Scientific Uncertainties

Current health effects research is focussing on the importance of chemical composition and the size distribution of PM. However, the chemical composition and the size distribution (including composition as function of particle size) of Ontario PM are only partly known. These data are necessary to improve the causal relationship between PM and human health effects.

If the health effects do depend on composition and particle size, the actual impact of particle reduction strategies may need further examination. Reductions of certain size ranges or particular chemical species, for example, may be more or less effective than "across the board" reductions.

5. Source apportionment, source estimates

A. Document Issues

To support the implementation of effective control strategies it is necessary to be able to assess the contribution of sources to observed PM concentrations. However this requires a detailed understanding of the emissions, transport, particle size and composition, and the complex interactions that result in the actual ambient PM levels.

The Compendium Document has a section on source apportionment. It concentrates on the state of the models necessary to undertake source apportionment. It quite rightly indicates that such models are in the early stages of development. In the measurement area it identifies limitations in data for ammonia, elemental carbon, organic carbon and nitrates. The understanding of the physical processes of formation, growth and break-up of particles is also highly uncertain.

B. Scientific Uncertainties

For acidic components ammonia is clearly important. It is the predominant basic gas in the atmosphere. Upon reaction with acidic gases that are either directly emitted or from the oxidation of sulphur, nitrogen, and VOC, particles are formed. Despite its importance, there is very limited information available on ammonia, either in terms of its emissions or its ambient concentrations. The lack of specific, Ontario-based data will result in substantial uncertainties in any estimate of the impact on PM levels resulting from a specific reduction in emissions (for an individual source or a source category). Due to the limited available source apportionment data it is very difficult to assign an impact on PM levels to specific sources or source types.

6. Efficiency of reduction strategies

A. Document Issues

If control strategies for emission reductions are implemented, one of the major questions will relate to the effectiveness of these strategies. This will involve all areas covered by the Compendium Document. The atmospheric studies components of this question revolve around the propagation of the scientific uncertainties identified above.

To determine costs, effectiveness of emission reductions, and required emission reductions to achieve certain AAQCs the Compendium Document generally uses linear relationships between emission reductions and exposure or ambient PM levels. However, this is primarily the

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consequence of the lack of detailed information. The actual impact of emission reductions on ambient PM levels and population exposure will depend on many details and most likely be far more complex.

B. Scientific Uncertainties

The uncertainty in background PM levels (see above) will propagate into the actual impact of emission reductions. Furthermore, the extent of emission reductions needed to achieve a certain absolute or relative reduction of ambient PM levels strongly depends on the background PM concentrations.

The reduction in direct particle emissions will most likely not be of equal magnitude for particles of all sizes. Since the atmospheric residence times of particles of different sizes are different, an emission reduction can not be linearly converted into a reduction of atmospheric particle concentration. Most likely the emission reductions will result in a less than linear reduction in ambient PM levels.

For similar reasons reduction of VOC emissions do not necessarily translate into a corresponding reduction of particulate matter formation. The potential to form secondary particulate matter from VOC oxidation is highly compound specific. Consequently the impact of VOC emission reductions on ambient PM levels will be extremely dependent on the types of VOC that are subject to emission reductions.

The impact of NO_x emission reductions on PM levels may be smaller than anticipated. Most of the particles seem (on average) to have a high sulphate content and probably are highly acidic. Under highly acidic conditions it may be possible that the amount of nitrate and other acidic gases contributing to particulate matter is not determined by the available acidic gas phase constituents, but by the acidity of the particles. The absence of relevant information on particle acidity, its size dependence and so forth, does not allow one to draw any firm conclusions. However it is evident that the impact of NO_x emission reductions on particle formation will be tightly coupled with reductions in sulfur dioxide emissions. For the same reasons the impact of ammonia emissions, or their reductions, will be connected closely to the availability of acidic gases (see above).

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II. Control Technology

The Compendium Document aims to give the necessary information on whether technologies, capable of controlling emissions to the level determined by AAQC, exist and can be implemented. Control technology also appears in the cost analysis section, where the cost of the implementation of these technologies is of vital importance. In this section of the report only the engineering/technical issues will be addressed.

The issues surrounding control technologies are primarily in the area of engineering. It appears to the Panel that the technology is well advanced and most of the control technology issues for Ontario are more related to implementation than to research on the technologies themselves. Consequently the information gaps identified by the Panel are mainly due to available information that is not included in the Compendium Document, as opposed to a lack of an understanding of control technology per se.

Major questions

The major questions that need to be addressed are:

1. *Are there control technologies available that are capable of reducing the emissions of PM and PM precursor gases?*

2. *Can new control technologies be instituted in Ontario?*

3. *Given there are a number of pollutants that require control and that multiple control strategies will need to be adopted, what are the issues around the integration of these control technologies?*

1. Existing Control Technologies

A. Document Issues

Overall, the Panel found that the documentation concentrates on the North American experience and does not adequately reflect activity in the more aggressive jurisdictions, such as Japan and Germany. Also in many cases the level of detail is insufficient for an adequate comparative analysis of technologies.

The relative advantages and disadvantages of various emission control devices are summarized in Table III.6.1 of the CD. While this table is a useful starting point, its value is limited. The basic operational principles for particulate and gaseous pollutant control devices are significantly different from each other. Therefore it would be helpful if the Table were expanded or supplemented to do the following:

- provide the basis for the descriptors (high, medium, low) used;
- include more technical information on the devices listed, such operating pressure, pressure drop, applicable particle size range, dust loading, type of flue gases; and
- include more devices, notably missing are techniques such as metal filters, ceramic filters, impact packed bed filters, catalysts, membrane separations, UV oxidation, and plasma reactors (Masuda et al. 1995; Lowless et al. 1995; Ruddy et al. 1993; Vercammen et al. 1997).

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SO_x removal technologies were reviewed in Section III.6.3 of the CD but in a very conservative fashion. The discussions and the review do not cover recent developments either in Ontario or elsewhere. Ontario Hydro (now Ontario Power Generation Inc.), Nova Scotia Hydro and Saskatchewan Power already have Flue Gas Desulphurization (FGD) (wet scrubber), dry limestone, and Electrostatic Precipitator (ESP) Limestone injection facilities respectively, and there is now a good deal of experience available in Canada and the U.S. Technologies such as advanced wet scrubbers (calcium-Gypsum, magnesium recovery, Stretford, TAKAHAX methods etc.), ESOX (conditioning agents and sorbent injections) etc. should be introduced (Energy Research Laboratory, 1991; Spark et al. 1989). It should be noted that 100% of Japanese and German industries have SO_x and H_2S control devices.

The NO_x control technologies in Section III.6.4 of the CD should be up-dated to include 1998 information. All power plants in Germany and Japan use Selective Catalytic Reduction (SCR) or Selective Non-Catalytic Reduction (SNCR) post combustion De-NO_x systems and several U.S. plants have already adopted similar systems. However, several new technologies such as ESONOX, electron beam etc. simultaneous NO_x and SO_x removal technologies are already in demonstration/commercial stages (Bartoszek et al. 1998; Hjalmarsson et al. 1992).

PM removal technologies are well discussed in Section III.6.5 for limited industrial areas, however, no general control devices were reviewed in the document. Tables III.6.3 & 6.4 are deceptive. Collection efficiencies are reported based on mass fractions ($\mu g/Nm^3$) but not separately for PM_{10} and $PM_{2.5}$. Furthermore, efficiencies are not given in terms of particle density ($\#pt./m^3$). The result is that the PM collection efficiencies for each of the devices in these Tables is reported higher for $PM_{2.5}$ than in actual fact.

VOC removal technologies were only addressed in a limited way in Section III.6.6. Strategic VOC control options for low and high VOC concentrations are significantly different (Ruddy et al. 1993; Vercammen et al. 1997), but no discussion of this issue was provided in the document. High control efficiencies as shown in Table III.6.5 only apply to high concentration VOCs (>50% in flue gas) but not for low concentration VOCs from high technology industries. The CD also needs a more thorough review of recent technologies such as biofilters, plasma, UV oxidation, advanced thermal incineration and catalytic oxidation techniques (Vercammen et al. 1997; Ruddy et al. 1993).

B. Scientific Uncertainties

In Sections III.6.2.2 and III.6.2.3 Good Engineering Practices versus Emission Control Devices is addressed. The point that is missing is that most of the options in the good engineering practices, or process modifications, have both technological and theoretical limits. (This is the reason why control devices have been used for approximately the past 100 years since electrostatic precipitators were invented (Kasahara et al. 1992)). NO_x and SO_x reduction by combustion controls are, for example, not independent. However, there is no comprehensive discussion of these limits. The relative costs of good engineering practices versus control devices are not discussed.

The major sources of uncertainty for the control technologies arose primarily from the *pollutant source time fluctuations* due to the initial concentration dependence of control device removal efficiency and *pollutant concentration detection techniques* (minimum concentration detection limit). Furthermore, the control of one pollutant by adding a new control device may well generate

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problems for already existing emission reduction devices. Fuel switches, for example, from high sulphur coals to low sulphur coals in power stations for reductions of SO_x emissions generates back discharge problems in existing electrostatic precipitators, reducing PM collection efficiency significantly (99.99% to 60 to 70% based on mass fraction). Hence modifications are required for existing PM control devices. The design that provides high PM removal efficiency (e.g. 99.99%) applies to PM_{10}, and modifications are required to obtain similar efficiencies for $PM_{2.5}$ alone. Technologies for transfer from PM_{10} to $PM_{2.5}$ control do exist; the major uncertainty will be cost estimations due to the needed integrated system concept of control devices.

2. Institution of Control Technologies in Ontario

A. Document Issues

The Compendium Document does not include discussion of the implementation of new control technology in Ontario. It does not indicate that new technologies are needed to reduce emissions. Rather it looks to the application of, so called "Good Engineering Practices", to the existing industrial processes to meet the intermediate target of a 10 to 15% emission reduction. However, there are no clear directions for how to institute "Good Engineering Practices".

In addition, the document does not address which regions, or industrial sectors, in Ontario would benefit most from the application of new control technologies. A priority listing of which pollutant, (PM, VOCs, or acid gases (e.g. NO_x, SO_2, H_2S)) should be the target of new technologies would be very useful.

B. Scientific Uncertainties

The uncertainties for new technologies fall into two areas. The first is technical - how well do they work? The second is what technologies are implemented and at what speed? This second area is discussed in this report in Section V: Cost-Benefit Analysis and is only briefly examined here.

For the controls implemented in Ontario, or for those to be implemented in the short term, the major uncertainty is in the control of the precursor gases rather than the primary PM. For these gases (VOCs, NO_x, and SO_x) the existing control technologies are 30 to 95% efficient for economical operations. Thus, both the efficiency and the variance of the efficiency are major uncertainties.

For very new, or not yet fully implemented technologies, the uncertainties in all aspects of their application are less well known than for the existing technologies, where local operational data exist. For such technologies, probabilistic modelling (e.g. Frey and Rubin, 1991) allows for simultaneous simulation of performance, emission and cost and produces information about the probability of obtaining desired results. The Compendium Document should reference this type of information as it provides uncertainty estimates on developing technologies.

The major sources of uncertainty arise from the rate at which controls are implemented. Clearly, the economy or activity of each industrial sector is an important factor. Also, installation of new control technology has a long lead-time for design, construction, and commissioning of new physical plant. Hence, long-term objectives must be clearly understood so each industrial sector can modify existing plants, or design new plants or processes incorporating appropriate emission control devices.

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3. Integration of Control Technologies

A. Document Issues

The control of primary and secondary PM requires control of both primary PM emissions and the precursor gases. The control devices for each of these components are different, therefore integrated pollution control devices are required for effective PM control. The Compendium Document treats the control of each pollutant separately without recognising this need.

Meeting emission standards for even a single pollutant probably requires multiple levels of control. These are usually sequential and can be installed at the same time or implemented over a longer time period. For SO_x, most industries in Japan and Germany already have several stages of de-sulfurization. KOBELCO Kakogawa Steel Works began using low sulphur fuels in 1973 but only 7% of the SO_x emission was reduced. Subsequently wet-scrubber technology was installed on the Coke Oven (the highest SO_x and H_2S sources in the plant) from 1974 to 1977, which reduced up to 50% of the emissions. Over the next 14 years lower SO_x and H_2S sources, such as Sintering plants and combustion heaters, were implemented to achieve a total 95% reduction from 1973 emission levels. The need for such strategic planning in stationary SO_x sources should be addressed in the document (Tanaka et al. 1992) as is discussed for the automobile SO_x sources in Section III.6.3.2. Similarly for stationary NO_x sources, most industries start with combustion control using low NO_x burners and/or combustion control such as re-burning to achieve up to nearly 50% NO_x removal. A second stage up-grade using SCR/SNCR or other post combustion control devices is needed for further reduction. For transportation (Section III.6.4.2), cold starts produce approximately 70% of gasoline engine NO_x emissions. Automobiles with advanced adsorption-catalyst hybrid systems are now available.

There is no discussion of integrated control technology. Technologies that target specific pollutants may, often adversely, impact emissions of other pollutants. Thermal VOC control techniques, for example, generate secondary NO_x and $PM_{2.5}$, and so would not be a viable control option in isolation. All pollutant control devices for VOC, NO_x, SO_x and PM must be considered as an integrated system. In a power plant, for example, depending on the fuel used (natural gas, coal or oil fired power plants), normally the integrated system consists of a high temperature electrostatic precipitator, SCR, wet-scrubber and heat exchanger (Energy Research Laboratory, 1991). The references in this section (Section III.6.7) should be updated.

B. Scientific Uncertainties

The impact of one control technology on another in an integrated system is still an area of substantial uncertainty.

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III. Exposure Assessment

Major Questions

The principle information gaps and uncertainties to be addressed under the Exposure Assessment section can be summarized as follows:

1. *Which of the many different types of particulate with various particle sizes (PM_{10}, $PM_{2.5}$, $PM_{10-2.5}$) and chemical speciation (sulphates, nitrates, metals, etc.) are primarily responsible for the health effects of PM?*

2. *What role do various gaseous co-pollutants (SO_x, NO_x, ozone, CO) play in contributing to the mortality and morbidity effects of PM?*

3. *How well exposure concentrations derived from central monitoring stations reflect personal exposure of individuals, especially for determining concentrations of PM in indoor air?*

4. *What is the magnitude and relative contribution of transboundary pollution from the central United States to ambient PM levels in Ontario, and what impact does this phenomenon have on projected health effects and emissions inventories?*

5. *How do size and speciation factors affect the deposition and uptake of PM particles in various regions of the lungs (lung dosimetry)?*

The exposure assessment step is necessary to relate the measured or projected estimates of PM concentration in ambient air compared with individual levels of exposure and dose.

1. Particle size and speciation

A. Documentation issues - *none*

B. Scientific uncertainty

There is no simple 'particle metric' to relate ambient atmospheric particulates air particulate to human health. At this time guidelines/standards generally use measures of PM_{10} (most widely used), and $PM_{2.5}$ (less frequently applied). However, this is predominantly due to the availability, or absence of measurements and not supported by mechanistic understandings of the health effects caused by particulate matter.

Regarding body burden assumptions, the document consistently discusses the lung deposition of inhalable particulate in terms that imply the particles are inhaled and persist in the lung for extended periods of time. However, environmental fine particulate in Ontario has significant amounts of ionic salts such as ammonium, sulphate, and nitrate. Chemical characterizations indicate that these ionic, water soluble species make up 25 - 75% of the particle mass. The

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solubility of these species in the lung tissues suggests that a large portion of the particulate will dissolve away over the period of hours to days and that a longer-term lung burden will not be realized for this particulate portion (Hicks and Pritchard, 1986).

2. Gaseous co-pollutants

A. Documentation issues

Dr. Rick Burnett's work (Burnett et al., 1998a) on co-pollutant relationships is being evaluated by other researchers. In addition, new co-pollutant studies are being developed. There will be confirming, supporting, and/or new evidence coming forward over the next year.

B. Scientific uncertainty

There may be considerable uncertainty in the estimates of health effects associated with particulate matter if co-pollutants are not adequately accounted for in the statistical models. Other co-pollutants, such as carbon monoxide, for example, demonstrate temporal co-linearity with inhalable particulate in the ambient atmosphere, and may also have a significant impact on the health of exposed individuals. These effects need to be accounted for in future studies.

3. Ambient PM concentrations versus personal PM exposure

A. Documentation issues

The CD does not address the problem of exposure to PM in indoor air, and its relationship to ambient air concentrations of PM_{10} and $PM_{2.5}$. An individual is usually exposed to a combination of outdoor and indoor air situations. There needs to be some estimate of outdoor air exposure and the contribution of outdoor air to indoor atmospheres -- perhaps based on a building-type ventilation estimate.

The CD does not list PM_{10} and $PM_{2.5}$ measurements that have been collected by Environment Canada in Ontario locations. These data should be included and the measurements compared to MOE data in similar locations.

B. Scientific uncertainty

The 'representativeness' of single stations to cover regional populations such as Toronto, Hamilton, and others needs to be clearly defined. The local pollution gradients in a region become important to the evaluation of health effects. In a populated area the monitoring sites are normally designed to measure 'general pollution' and not to be affected by strong local sources (e.g. freeways). High spatial or temporal variability of exposure levels may have a very substantial impact on health effects, especially since non-linear dose-effect relationships cannot be ruled out.

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4. Transboundary pollution

A. Documentation issues

The CD provides an analysis of PM air pollution specifically delimited to Ontario, but does not examine the health effects of air pollution on a continent wide basis. The CD does describe the basic transport patterns of transboundary air pollutants originating in the Central United States. and travelling to Ontario. However, the CD fails to examine the amount of PM being transported from Ontario to Quebec and the Northeastern United States and what the estimated effect of this is on the health of individuals in other provinces/states.

B. Scientific uncertainty

A significant component of particulate matter in Ontario (whether it is primary or secondary) is derived from transboundary emissions. The document does not identify this 'transboundary anthropogenic component' but instead assumes that all Ontario-based ambient particulate is of Ontario origin. It goes on to estimate the effects of pollution control measures and the effect these will have on the final particulate concentration in the air. A 50% reduction in Ontario, for example, will result in a 50% reduction in airborne particulate in the Ontario airshed. This is not realistic, as a 50% reduction in Ontario emissions will reduce only the non-background (i.e. that which is not natural or of transboundary origin) component. This will have a significant effect on the calculation of cost/benefit ratio of air pollution controls. To the extent that future changes in transboundary PM emissions from the United States are strongly influenced by new EPA regulatory standards, this type of uncertainty is indeterminate because it is based on political contingencies.

The MOE and Environment Canada possess considerable expertise in transboundary, regional, and local scale modelling. In particular there is a need for a clarification of the influences of air mass motions across North America on the motion of particles and smog. One option is to conduct 'back trajectory analyses' for a representative number of days to help identify the nature and sources of the long-range transport component of PM in Ontario. In addition, the trajectory study will be useful when estimating the component of Ontario PM that migrates out-of-province to Quebec and the Northeastern United States. Where possible, the trajectory analysis should attempt to estimate the levels and identity of secondary particulate precursors, primary particulate, and secondary particulate formation.

5. Particle characteristics

A. Documentation issues

The CD does not adequately focus on what happens once the particulate is deposited in the lungs. This information is necessary to relate external exposure in inhaled air to internal tissue exposure in various regions of the lung, specifically the large airways (conduction zone) and broncho-alveolar zone (gas exchange region).

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B. Scientific uncertainty

The large solubility component of the aerosol suggests that much of the particulate deposits as a soluble salt. An understanding of the chemistry of the deposited particles and the co-pollutants is important. How does it react, absorb, or transfer through the lung membranes and how is a soluble aerosol cleared? The residence time in the lung for soluble components is expected to be much less than is predicted using conventional 'refractory aerosol' studies.

In the calculation of the health benefits accrued from particulate control measures, the analyst has assumed that all particulate reduction will be beneficial. This approach is one that is used for long-term persistent toxins (e.g. PCBs, Dioxins, Lead) where the contaminant may exist in the body and build up over time and the risk of illness/death increases with body burden. However, in light of the fact that much of the particulate is made up of water soluble ionic salts that may cause a short-term insult or episodic effect, but little or no long-term persistent effect, this may not be an appropriate control concept.

IV. Health Effects

Major Questions

The knowledge gaps and uncertainties related to characterizing the potential health effects of PM on morbidity and mortality can be summarized as five principle questions:

1. *To what extent is the available evidence sufficient to infer a causal relationship between PM exposure and cardiopulmonary mortality and morbidity?*

2. *Is the imputed causal relationship associated with a significant reduction in life expectancy or quality of life, or does it reflect the advancement of death by a few days of chronically ill and elderly persons with end-stage cardiopulmonary disease (harvesting effect)?*

3. *If a causal relationship is accepted, which PM component is most directly involved in specific health effects, and to what extent is PM a surrogate for gaseous air pollutants (or synergistic with other air pollutants in an urban air pollution mix)?*

4. *Assuming a causal relationship exists for PM_{10} or $PM_{2.5}$, what is the dose-response relationship between ambient concentrations of PM_{10} or $PM_{2.5}$ and specific health effects, both for mortality and morbidity?*

5. *Does the risk characterization for population mortality or morbidity necessarily entail a strictly linear nonthreshold dose-response model, where health impacts are strictly proportional to ambient PM concentrations, no matter how small?*

The Health Effects Section of the CD appropriately addresses the first question (causation) and fifth question (risk characterization) in a thorough manner. The second question (harvesting effect) is briefly discussed in the CD, but more extensive examination of this question is merited by its importance in policy formulation. The third question (PM components) is addressed at

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considerable length in other sections of the CD, and its implications for interpreting the findings of the epidemiological studies is extensively discussed in the Health Effects section.

However, a serious weakness in the CD is the general lack of information about the fourth question (dose-response). Specifically, a detailed description of the methodology and assumptions underlying the derivation of the quantitative dose-response relationship is not provided in the CD. Part of this difficulty appears to be related to the use of a proprietary model for estimating the health effects and the benefits of reduced exposure to PM.

1. Causality

A. Documentation issues

The first question of causality is discussed quite systematically in the CD and is presented in sufficient detail to allow for reasoned discussion of the relevant issues pertaining to the inference of a causal relationship. Most of this discussion is based exclusively on an extensive recapitulation of the previously developed Science Assessment Document on Particulate Matter (PM SAD) produced by the Working Group on Air Quality Objectives and Guidelines (WGAQOG), especially the summary chapter (Chapter 13). This secondary documentation approach is advantageous to the extent that it provides a consistent and well articulated view of the 'state of the science' in a well documented and thoroughly reviewed consensus document developed in a Canadian context.

However, there are also several disadvantages to adopting the findings and conclusions of the PM SAD at face value. First, within the CD it is sometimes difficult to follow the precise line of reasoning for arriving at conclusions about the evidentiary criteria presented in the PM SAD. This section of the CD appears to have been faithful to the content and spirit of the PM SAD report, but inevitably any of the finer nuances and cautionary explanations are omitted or obscured. Second, the CD fails to make clear whether critical findings and conclusions about causality are in fact intended as a faithful reflection of the PM SAD report -- or alternatively whether the CD treats the PM SAD as a point of departure with subsequent interpolations and re-examination of some of the scientific evidence by the CD authors. Third, one important section of the PM SAD is missing from the CD discussion -- Chapter 14 of the PM SAD which discusses the criteria for deriving a suggested Reference Level (RL) for PM_{10} and $PM_{2.5}$ (also sulphate). While this omission does not directly compromise the discussion of causation, it leaves open the question of how the 25 ug/m^3 Reference Level was developed for inclusion in the later section on Estimate of Health Impacts. Finally, by treating the PM SAD as a canonical source document, any new research findings are difficult to incorporate into the existing causality framework. A brief 'Recent Developments' section has been added in the CD to provide some updated scientific findings from the literature, but this information is not well integrated into the discussion.

The references in this section related to Ontario Medical Association and the David Suzuki Foundation are policy position papers that cannot be considered as scientific evidence. Their inclusion in the CD is of questionable relevance to the causation question.

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B. Scientific uncertainties

The CD correctly identifies a fundamental problem with determining causation for PM health effects, the heavy reliance on epidemiological studies for detecting and quantifying adverse health effects. Ideally, for a satisfactory hazard characterization, there should be a triangulation of evidence gathered by multiple methods -- epidemiological studies in exposed human general populations, clinical epidemiological studies of those with cardiorespiratory disease, controlled laboratory human exposure studies, and toxicological studies in experimental animals. The CD has therefore appropriately delineated and discussed the available epidemiological findings using a weight-of-evidence framework based on the causality criteria first elaborated by Bradford-Hill for cigarette smoking studies in the early 1960's. The CD adequately describes these causality criteria, although the criteria are discussed more fully in the PM SAD document.

Regarding the consistency criterion as reviewed in the CD and PM SAD, most epidemiologists now accept that a broadly consistent statistical association across many epidemiological studies can be found between PM exposure measured as ambient PM concentrations and excess cardiopulmonary mortality and morbidity. The CD also correctly notes that two large-scale cohort studies -- the Harvard Six City Study (Dockery et al., 1993; Schwartz et al., 1996) and the American Cancer Society study (Pope et al., 1995) -- generally support the findings of previous time-series and cross-section studies that originally uncovered these health effects. However, the CD fails to balance its assessment by acknowledging that a third high-quality study -- the California Seventh Day Adventist Study (Abbey et al., 1995) -- detected no statistically significant elevation of cardiopulmonary mortality. While lack of adequate sample size and statistical power might explain this negative finding, as well as possible over-control of confounding variables such as weather, this controversy is not sufficiently examined either in the CD or in the PM SAD.

The CD also provides a good discussion of the importance of obtaining a reasonably consistent monotonic dose-response relationship across many different studies in different localities, but is less successful in placing these findings in context. The range of mean 24-hour particle sizes encountered in the critical epidemiological studies (CD Table III.5.1) is somewhat misleading, because the statistically significant health effects for mortality (and some morbidity endpoints) occur mainly at the higher end of the reported PM concentration range, whereas at the lower exposure level below about 25 ug/m^3 PM_{10} the excess mortality risk is not statistically significant.

The range of relative risk (RR) estimates in the majority of PM mortality studies is approximately RR = 1.03 - 1.10 for the highest levels of PM exposure (i.e., the magnitudes of elevated risk are about 3 to 10% above baseline). While large-scale studies are clearly capable of detecting statistically significant relative risks in the range of 1.0 to 1.5, the absolute effect size of these risks is so small that it is very difficult to conclusively eliminate all potential sources of bias and confounding, even in well controlled studies with sophisticated regression techniques. Regression analyses that under-control for potential confounders, such as the meteorological conditions and gaseous co-pollutants associated with PM, could conceivably attribute mortality and morbidity effects to ambient PM concentrations when weather factors or co-pollutants (especially ozone) actually provide an alternative explanation.

The CD would benefit from a discussion of the 1996 Health Effects Institute (HEI) re-analysis (Samet 1998a, 1998b) of the Harvard Six Cities Study, which has effectively reduced, but not eliminated, the

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problem of dealing with weather and gaseous co-pollutants as potential confounders in complex regression models. The HEI re-analysis also lends further support to the robustness of the statistical regression models as described in the CD.

Concerning specificity, the CD addresses two issues -- the specificity of exposure to PM and the specificity of health effects. There are a variety of reported health effects endpoints discussed in the CD, and their common linkage to cardiopulmonary disease is reasonably explained. To some extent the specificity of effect may be considered overstated, because the acute and chronic mortality effects of PM may represent related but distinct pathological processes -- for example, induction of acute inflammatory mediator release on a short-term basis and cytokine induction of chronic degenerative lung disease on a long-term basis. This problem is briefly dealt with in the CD but requires more extensive examination with respect to possible mechanisms of acute and chronic toxicity.

Specificity of exposure is less easily addressed. As a complex mixture of particles with varying sizes and chemical speciation, the specificity of exposure is inherently more difficult to unravel than for gaseous air pollutants. This issue is discussed further in the Section III: Exposure Assessment.

Regarding coherence, the CD is not clear about the implications of attempting to combine the findings of acute effects studies, such as daily mortality studies using time-series observations, with the findings of chronic effects studies using longitudinal cohort designs. For cardiopulmonary mortality, both types of studies appear to consistently demonstrate elevated cardiopulmonary mortality associated with high concentrations of PM. Although the cohort studies are in general agreement with the time-series studies regarding excess risk of mortality, the possible causal linkages underlying the two sets of studies is not clearly explained in the CD, mainly because the basic toxicological mechanisms remain obscure. PM-associated long-term mortality observed in the cohort studies, for example, might be reasonably explained by the observed increases in chronic obstructive pulmonary disease (COPD) and pneumonia (and associated ischemic heart disease) detected in the same studies. However, these findings are not themselves sufficient to explain the elevated 24-hour mortality observed in time-series studies, which reflects an acute response to elevated PM exposure over too short a time period to be attributable to chronic effects.

The presentation in the CD of a 'pyramid of effects' relating PM-associated pulmonary morbidity (e.g. pulmonary symptoms, asthma, cardiopulmonary hospitalizations) to PM-associated mortality is an interesting but not persuasive argument for coherence, mainly because these health effects reflect risk estimates derived from a predictive dose-response model rather than empirical findings from the major epidemiological studies. A pyramid of effects should be based on the actual incidence of excess mortality and of excess cardiopulmonary morbidity observed in an epidemiological study of PM-associated health effects. The pyramid is not always coherent in such studies – for example, the incidence of mortalities may be greater than the number of hospital admissions.

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2. Harvesting effect

A. Documentation issues

The CD discusses the possibility of PM-associated hastening of short-term mortality in the frail elderly -- a harvesting effect -- at various points throughout the discussion of causality. However, it fails to adequately highlight the harvesting effect as a critical problem concerning the meaningfulness of elevated short-term daily mortality in relation to long-term annual mortality. The latter measure is much more meaningful to public health because it reflects a significant reduction in life expectancy.

B. Scientific uncertainties

These were largely unresolved at the time the CD was written. A recent analysis on the 1974-88 Philadelphia cohort (Zeger et al. 1999) provides evidence that a harvesting-resistant time series regression analysis demonstrates a significant and meaningful long-term mortality from PM exposure. The annual mortality effect thus appears to be at least as large as daily mortality, although further studies are required to confirm this finding.

3. PM components

A. Documentation issues

The CD discussion of issues concerning the selection of appropriate exposure measures is limited (particles vs. mass vs. other options, daily vs. monthly vs. yearly, peaks vs. averages) partly by the nature of existing exposure data available for modelling purposes.

PM is a complex mixture of particles of varying size and chemical speciation. Ambient exposure concentrations to each of the major sub-fractions of interest, PM_{10} and $PM_{2.5}$, are often highly correlated, which leads to a high degree of collinearity between these two covariates in regression analyses. Hence, it is difficult in most epidemiological studies to determine the relative contribution of PM_{10} and $PM_{2.5}$ to overall respiratory mortality and morbidity. The CD has appropriately identified the relevant evidence that $PM_{2.5}$ may represent the more important of the fractions regarding health effects, although the validity of this conclusion remains in doubt. Discussion of the EPA Clean Air Scientific Advisory Committee's (CASAC) assessment of PM_{10} and $PM_{2.5}$ as causative or surrogate agents (CASAC 1995, 1996) would have been informative. The CASAC panel for example, has suggested that the case for $PM_{2.5}$ as causal is perhaps overstated, but that $PM_{2.5}$ as surrogate measure for the toxic sub-fraction(s) of airborne particulates is probably acceptable.

B. Scientific uncertainties

It does NOT follow that reduced concentration of an exposure surrogate will reduce mortality. The recent epidemiological findings by Burnett (1998b) are crucial to the inference of causality and the relative contribution of PM and gaseous co-pollutants to the causation of mortality and morbidity.

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The CD notes that projections of $PM_{2.5}$ effects cannot be made with any exactitude because of the lack of available Ontario data (Section III.5.2.2, p. III.5.17). However, the CD also reports that preliminary analysis based on a few Ontario urban sites in the NAPS database indicates that 'over 90% of the premature mortalities and hospital admissions are due to $PM_{2.5}$. This finding needs to be further substantiated.

One way to examine whether coarse particles are a risk for mortality is to identify localities with high concentrations of coarse, but not fine, particles. Recent epidemiological studies on PM-associated exposure to coarse particulates ($PM_{10-2.5}$) in the absence of fine particulates ($PM_{2.5}$), for example, support the contention that coarse PM from windblown dust is not associated with mortality risk (Schwartz et al., 1999).

4. Dose-response relationship

A. Documentation issues

The derivation of the various mortality and morbidity risk coefficients for characterizing dose-response relationships is reasonably well documented in the AQVM Methodology Manual as referenced in the CD, but these issues are not discussed at all within the CD itself. The HB model, for example, provides three alternative values for the mortality risk coefficients used to estimate annual PM-associated mortality in Ontario. These values are labeled high, midpoint, and low as if they were meant to account for parameter uncertainty. However, while the high and medium mortality coefficient values in the model are derived from the arithmetic mean and statistical upper bound of the acute mortality risk coefficient of several times-series PM studies, the low value is apparently derived from the arithmetic mean of several chronic cohort PM studies. Such mixing of parameter uncertainty and model uncertainty in a single set of mortality risk coefficients is highly unusual and of questionable validity. Effectively, the midpoint and high mortality predictions are based on acute data, and the low risk prediction on chronic data.

B. Scientific uncertainties

The CD and PM SAD correctly report that there is a roughly linear dose-response relationship in observable range of PM concentrations, with no observable threshold at any concentration level. However, the CD does not adequately explain that the absence of a detectable dose-response threshold does not disprove the possibility of a threshold.

Typically, most time-series studies indicate that the mortality health effects becomes non-significant at about the 25 or 20 ug/m^3 mean 24-hour PM_{10} concentration. Thus any inference of mortality dose-response below these levels is based on mathematical extrapolation of the modelled dose-response curve rather than on empirical findings. While dose extrapolation is a commonly accepted method in quantitative risk estimation, it is dependent on a well-founded mechanistic basis substantiated by extensive toxicological evidence in animal or human studies. For PM, such evidence of toxicological mechanism is lacking.

In addition, the large exposure misclassification inherent in time-series studies obscures the shape of the dose-response curve in the exposure region below about 25 ug/m^3 PM_{10} -- consequently, any

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determination of possible threshold or sub-linear dose-response behaviour is effectively precluded. The exposure misclassification problem is lessened for the longitudinal cohort studies, due to averaging out of exposure classification errors over a seasonal or annual time period. These latter studies focus on chronic (annual) mortality, which is of questionable relevance to acute (24-hour) mortality. Hence the provisional acceptance of a linear non-threshold dose-response model should be viewed as a regulatory 'default assumption' based on a serious knowledge gap.

Moreover, the threshold concept does not likely hold in human populations due to range of inborn sensitivities and variations in co-exposure and other environmental conditions. This requires a detailed exposure-response matrix for sensitive sub-groups and heavily exposed sub-groups. Those with cardio-respiratory disease, for example, will likely have a lower threshold for increased symptoms than the general population and a lower threshold than required for mortality effects. Such heterogeneity should be recognized, modelled, and further researched.

5. Risk characterization and health effects modelling

A. Documentation issues

There are deficiencies in the documentation of the estimated health effects in the CD Health Effects Section. The prediction of PM_{10} associated health effects for Ontario are provided in the CD with virtually no preamble or methodological exposition, as a summary table (CD TABLE III.5.2) that presents precise estimates of annual mortality and respiratory morbidity. There are no explanations given in the CD concerning the data sources or means of derivation of the mortality and morbidity risk coefficients, and the risk coefficients themselves are not presented.

The CD does provide a reasonably clear conceptual description of the methodological approach used by the Hagler-Bailly (HB) model to estimate the predicted annual mortality and respiratory morbidity associated with PM_{10} exposure across the population of Ontario. However, the CD engenders considerable confusion concerning the degree of equivalence between the HB model as reported in the CD and the Air Quality Valuation Model (AQVM) developed by Hagler-Bailly for Environment Canada. It is assumed, but not certain from the CD, that the two models are essentially equivalent in structure and functionality, although the details of the models may differ (e.g. HB as described in the CD deals with Ontario regions only while AQVM deals with all regions of Canada). The AQVM model appears to be a later derivative of HB model.

Both the HB and AQVM models are proprietary spreadsheet computational models owned by Hagler-Bailly consultants, which means that these models have not been made available for testing by the scientific or regulatory community. While there are no fundamental defects apparent in the HB or AQVM model as described in the methodological literature provided by Hagler-Bailly (Hagler-Bailly, 1996; Ostro and Chestnut 1998), the model has not been subjected to close examination in the CD concerning its model structure, computational methods, data inputs, underlying assumptions, and various strengths and weaknesses. In other words, the model lacks both transparency and external validation. Models in the public domain, for example the Tracking and Analysis Framework (TAF) model, allow full access to model documentation and model software codes, and provide a detailed analysis of model performance in predicting health effects and health benefits (Burtraw et al. 1998).

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Moreover, the CD fails to make clear how the HB model deals computationally with uncertainty in model input values, such as mortality risk coefficients of willingness to pay (WTP) valuations on mortality. Although the HB model computations are based on a probabilistic Monte Carlo simulation technique, the model output is structured to provide only deterministic risk estimates in the form of a multi-parametric sensitivity analysis, not a true uncertainty analysis. Such important methodological details are essential, given the reliance on the HB model predictions for PM_{10}-associated mortality and morbidity estimation within the benefit-cost framework of the CD. This issue is further discussed in the section on Cost-Benefit Analysis.

B. Scientific uncertainties

Risk characterization entails the quantitative assessment of population-wide health effects (e.g. Ontario population). This is accomplished by multiplying the estimated time-weighted mean annual exposure concentrations of PM_{10} for persons in various regions of Ontario by the risk coefficients for mortality and morbidity endpoints.

For estimating the mortality and morbidity health effects associated with PM_{10} exposure, the HB model assumes that an exclusively linear non-threshold dose-response exists at all levels above zero exposure. Given that about 5 ug/m^3 PM_{10} represents an irreducible background concentration, the predicted health effects can be subtracted as unavoidable natural exposure, but this subtraction does not represent a threshold model.

Although the issue of whether a threshold exists for PM-associated health effects remains unresolved, it is not appropriate in risk characterization to rely solely on a default assumption of linear nonthreshold dose-response to the exclusion of possible threshold models. The HB model provides no alternative model formulation to assess the possible impact of an effect threshold on predicted mortality and morbidity projections. The HB model, for example, provides no alternative model predictions based on a possible threshold values equivalent to the PM SAD Reference Level (e.g. 25 ug/m^3 PM_{10}). This omission is particularly unfortunate, considering that the World Health Organization (WHO) EURO guidelines state that extrapolation of the PM dose-response relationship below the 20 ug/m^3 PM level is not acceptable for estimating potential health risks.

This omission is especially important considering that the great majority of person-days of PM_{10} exposure in Ontario are in the range well below the Reference Level of 25 ug/m^3. To the extent that reductions in PM_{10} exposure concentrations in this lower region may accrue minimal or negligible health benefits for sub-threshold or sub-linear regions, the HB model may grossly inflate the estimated health benefits of PM_{10} reductions below about 25 ug/m^3. The appropriate action in situations of fundamental ignorance about threshold is to present a series of health benefit projections based on alternative threshold model assumptions. Such threshold-dependent sensitivity analysis has been included as a feature in other health benefits models for PM_{10}, such as the TAF (Tracking and Analysis Framework) model (Burtraw et al. 1998). In the absence of reliable threshold information, it is also possible to apply a range of elasticity functions to assess the possible effect of sub-linearity in the low-dose region of the dose-response curve.

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V. Cost-benefit Analysis

Major Questions

The knowledge gaps and uncertainties in the CD related to conducting a cost-benefit analysis (CBA) can be summarized as 5 principle questions:

1. *Does the assumption of a linear nonthreshold dose-response function provide a reasonable basis for estimating the projections of health benefits arising from reductions in ambient PM_{10} concentrations?*

2. *Do the approaches used for estimating the monetized health benefits valuations for reductions in mortality risk and morbidity risk valuation accurately reflect societal expectancies concerning health protection?*

3. *Does the exclusion of certain risks and benefits from the CBA compromise or bias the quantitative findings of the analysis?*

4. *How realistic are the underlying assumptions for estimating the projected costs of control to industry in Ontario from targeted reductions in air emissions of PM (or PM precursors)?*

5. *How well do the quantitative models used for estimating projected benefits and costs deal with uncertainties in model variables, model valuations, and model assumptions?*

The section of the CD dealing with Cost-Benefit Analysis (CBA) describes the methodological approaches used in estimating two quantities:

- health benefits - the annual monetized benefits of morbidity and mortality reduction in the Ontario population, resulting from various projected levels of reduced ambient concentrations of PM_{10}; and

- cost of control - the estimated costs of control incurred by Ontario industries in achieving targeted reductions in ambient PM_{10} levels, based on the estimated reduction in industrial emissions required to achieve a specified ambient PM_{10} level.

Health benefits were evaluated in the CD using the Hagler-Bailly (HB) model, an early version of the Air Quality Valuation Model (AQVM) developed by Environment Canada and Health Canada. Both models use a damage function approach to compute impacts and benefits with the scientific injury assessment process and the economic theory of environmental impact valuation (see Hagler Bailly Consulting (1996)).

The CD presents a cost analysis of particulate matter emission control scenarios in Ontario using 1990 data that were taken from the Residual Discharge Information Systems. These cost projections used a previous version (SENES (1992)) of the AERCO$T™ model developed for Environment Canada by SENES (see SENES (1995) and SENES (1996)). AERCO$T™ is a proprietary tool used to estimate costs for air pollution control options. According to the CD, the

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MOE has asked Environment Canada to update their Ontario PM_{10} emissions inventory with AERCO$T™, but this update was not provided to the MOE in the CD time frame. Consequently, updated cost estimates (using AERCO$T™) for air pollution controls using 1995 data are not yet available.

1. Dose-response function (threshold)

A. Documentation issues

The Hagler-Bailly model (HB) and Air Quality Valuation Model (AQVM) are the names given to the computer modelling package developed under contract by Hagler-Bailly consultants for Environment Canada/Health Canada. The assertion in the CD that it does not use the AQVM appears technically correct, since AQVM is Canada-wide and HB is Ontario-specific. But there is, nonetheless, a lot of AQVM-related material within the Compendium Document (CD) for IP/RP. Apparently, all of the numerical inputs to the CD calculations comes from the AQVM, as summarized in the document *Air Quality Valuation Model (AQVM) Report 2: Methodology* (Hagler-Bailly, 1996).

The HB and AQVM models consist of two 2 modules which are used to estimate:

a) the adverse health impacts (mortality and various morbidity endpoints) as a function of incremental daily PM_{10} ambient exposure, and

b) the monetized value of the potential benefits of PM_{10} reduction, based on valuation of life for mortality improvements (using WTP estimates), and various monetizations for morbidity endpoints (days hospitalized, etc.).

The HB model does not include a module for the analysis of cost of control for the PM_{10} reduction scenarios.

The AQVM Report 2 (Methodology) document (Hagler-Bailly, 1996) cited in the CD apparently supplies the following input values for the CD health impact calculations (Tables refer to AQVM Report 2):

- baseline ambient PM_{10} levels by Ontario census tract (AQVM Table 3-6).
- exposure-response coefficients from AQVM Table 4-2, using the HB mortality risk coefficients derived by meta-analysis of the dose-response slopes observed in PM_{10} epidemiological studies -- especially prospective studies such as the Harvard Six Cities Study (Dockery et al., 1993; Schwartz et al., 1996) and the American Cancer Society (ACS) Study (Pope et al., 1995).
- economic valuations of mortality (AQVM Table 5-3) and morbidity, which becomes TABLE IV.11 in the CD. These are obtained through willingness-to-pay (WTP) and cost-of-illness (COI) estimates produced by Hagler-Bailly.

The overall health impact methodology clearly follows the HB approach, with AQVM Report 2 values for most/all input parameters. The major difference between the AQVM Report 2 and the CD

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calculations is that the CD calculations are Ontario-specific (not Canada-wide), and are more focussed on PM_{10} (not acid rain). The mortality risk coefficients used to estimate health impacts are somewhat different than those reported in Ostro & Chestnut (1998) (the latter are U.S. values based on a slightly different derivation of the epidemiological studies' risk coefficients) -- but the methodological approach is exactly the same. Some of the morbidity risk coefficients (e.g. chronic bronchitis) are identical in the Canada (AQVM Report 2) and the United States. (Ostro & Chestnut (1998)). The remark by MOE in response to CPPI's stakeholder letter (CD Appendix E p.32) that AQVM was 'not used in the dose-response modelling' for PM_{10} health effects only makes sense if the above considerations are approximately true.

B. Scientific uncertainties

The HB model uses a damage function approach to compute impacts and benefits. Within its design limitations, this model is reasonably well formulated (the assumptions underlying the model are explicitly described in Hagler Bailly Consulting (1996)). Although there will always be some controversy associated with the manner in which some non-monetary items are calculated or parameters chosen (e.g., the value of a statistical life and the discount rate chosen), the model did provide some sensitivity analysis with regards to the willingness to pay values per incident or death (low, central and high).

However, the HB model is flawed by its over-reliance on a linear nonthreshold dose-response function for all estimates of the projected health benefits from ambient PM_{10} reductions. According to the CD "research has revealed that many contaminants, including PM_{10} and $PM_{2.5}$, exhibit no ambient concentration thresholds above zero."(Section IV.2) Unfortunately, no studies are cited to back up this assertion (at least not in the cost-benefit section) - nor is it evident that the no threshold case has been adequately substantiated. To account for this uncertainty, the benefit analysis should explore the sensitivity of health benefits to the introduction of a potential threshold for PM_{10} health effects. Here the days in which baseline concentration is below this threshold will not register benefits of PM_{10} reductions. Burtraw et al. (1998) use a threshold in effects at a 24 hour average concentration of 50 ug/m^3 PM_{10} while Lee et al. (1995) use a 24 hour average concentration of 30 ug/m^3 PM_{10}.

2. Valuation of mortality risk

A. Documentation issues

A notable omission in the CD is the lack of discussion of potential health effects and health benefits for populations beyond the boundaries of Ontario. To the extent that emission reductions in Ontario would result in lower ambient PM levels in other jurisdictions downwind from Ontario, there should be a consideration made in the risk estimation and benefits analysis about the impact of mortality and morbidity reduction in these geographical localities. Otherwise the imputed life valuation for the citizens of Quebec, New Brunswick, and the Northeastern United States is essentially zero, which is neither politically correct nor scientifically valid.

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B. Scientific uncertainties

In cost-benefit analysis all the costs and the benefits are expressed in money terms. This makes cost-benefit analysis a useful tool for determining whether a program is worth undertaking, since both benefits and costs are expressed in the same units (money). Of course many costs and benefits, particularly the value of human life, are problematic to evaluate in money terms and their evaluation is a subject of active discussion among economists (Schelling (1973), Fuchs and Zeckhauser (1987)).

A wide range of government policies - from health care to the environment - seek to reduce risks to human life. Pratt and Zeckhauser (1996) suggest that in a democratic society, expenditures on such policies should be directed by the preferences of the members. The metric, therefore, should be willingness to pay (WTP) to reduce risk.[3] Ideally, economic valuation of changes in health effects incidence reflects the full quality-of-life impact to the affected individuals including out-of-pocket expenses (e.g., lost income and medical costs) and less tangible effects on well-being such as pain, discomfort and restrictions in non-occupational activities (Ostro & Chestnut (1998).

The greatest uncertainties in valuation of health benefits centre on the methods for deriving a valid set of monetized values for PM-associated mortality and morbidity. The Mortality Risk Valuation is especially important because it is very heavily weighted in the aggregated projections of health benefits within the HB model. The uncertainty in this area does not lie in the decision to use WTP measures for mortality risk reductions but in actual measuring and valuing of mortality. The majority of the literature on the value of a statistical life (VSL) provides estimates for reducing risks of accidental and immediate death primarily among the working age population (averaging 40 years old). According to Burtraw et al. (1998), however, particulate matter exposure may lead to higher probabilities of premature mortality in ways that disproportionately affect individuals when they are old. The latter suggests that the WTP for a risk reduction realized in the future is likely to be much lower if one has to pay today for benefits realized when one is much older. Jones-Lee et al. (1985) found that the value of a statistical life for the 65 years and older group was approximately 75% of that of the 40-year-old participant. Like Burtraw et al. (1998), the CD should also acknowledge this uncertainty by adjusting the VSL downwards based on life-years remaining so as to provide a lower bound to the VSL estimates. More research is needed to improve the basis for valuation of small changes in mortality risks experienced late in life (Johannesson and Johansson (1996)).

More recent economic critiques have argued that the use of the value of a statistical life as a basis for valuing health risks from air pollution, instead of a more appropriate measure of quality adjusted life years (QALYs) lost could grossly overestimate mortality benefits. Cost-utility analysis is a more recent technique in health program evaluation, which overcomes the problem of trying to assess health effects

[3] The Panel wishes to make clear that its comments are targeted at how correctly the WTP approach is applied to the cost-benefit analysis presented in the CD, not that it is necessarily justified as the preferred method for assessing strategic options with respect to PM or other air pollutants. A variety of other socio-economic methods that do not require monetizing assumptions for life valuation and health valuation are available as alternatives to cost-benefit analysis. The ALARA methodology (As Low As Reasonabably Achievable), for example, might be employed – what is 'reasonably' achieveable in the way of risk reduction is then determined by the result of applying a minimum exposure standard, possibly based on cost-effectiveness criteria (cost-of-control per life saved). Cost-effectiveness criteria are considered as an important component of many formulations of the Precautionary Principle (see Chapter 3, 'Fundamental Considerations').

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in money terms (as in cost-benefit analysis) and of measuring life years gained irrespective of their quality (as in cost-effectiveness analysis). The outcome of the program is measured by the improvement in the quality of life, usually measured as healthy year equivalents (HYEs), quality adjusted life years (QALYs), or well years. This "wellness" adjusted outcome is derived by weighing the original outcome (life years) by a utility value on a scale from 0 (which could be anchored as death) to 1 (which could be anchored as optimum health). The use of a concept such as QALYs permits all degrees of disability to be compared to one another. The utility value is obtained by judgment, values from the literature, or values from measurement on a sample of subjects. The methods that may be used to measure quality of life are the subject of a growing literature and debate (Commonwealth of Australia (1993), Johannesson & Johansson (1997), Reid (1998), Buckingham (1993)).

The mortality risk valuation debate is ongoing. To improve the CD's benefit analysis, the uncertainties listed above should be highlighted, sensitivity analyses should be conducted on WTP measures and the assumptions regarding the calculations made should be transparent for all stakeholders to assess.

3. Excluded non-health benefits

A. Documentation issues

The CD only described health benefits (mortality and morbidity) associated with emissions reductions. Using Text Box 1 in the CD (Section IV.4, p. IV.7), an ideal cost-benefit analysis for environmental initiatives would quantify all the relevant benefits of proposed standards or programs including damages and costs avoided and reduced, new and increased opportunities for human use and enjoyment and perceptions of aesthetic aspects of environmental quality.

B. Scientific uncertainties

The following benefits are excluded from the CD: aquatic and soil effects benefits, visibility effects benefits, the effects benefits to material and cultural resources, nonuse of ecosystem health, recreational forests, agricultural and commercial forestry. Burtraw et al. (1998) study the costs and benefits of reducing air pollutants related to acid rain (SO_2, NO_x, PM_{10}) and include health effects benefits (mortality and morbidity), aquatic and soil effects benefits, and visibility benefits which combined recreational and residential benefits. We must note that this study was undertaken using the Tracking and Analysis Framework (TAF) to conduct the cost-benefit assessment. TAF is a non-proprietary model constructed with the *Analytica* modelling software and available to anyone via the Internet (http://www.lumina.com/taf/index.html). Unlike the approach taken in the CD, Burtraw et al. (1998) examine both costs and benefits using an integrated assessment in that they explore costs and benefits under a consistent set of assumptions and sensitivity cases. The lack of integration in the CD is discussed below in Section 5.

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4. Cost modelling

A. Documentation issues

As noted earlier, the CD presents a cost analysis of particulate matter emission control scenarios in Ontario using 1990 data. These estimates are to be updated using 1995 data and a proprietary tool called AERCO$T™ developed under contract by SENES for Environment Canada (see SENES (1995) and SENES (1996)). The estimates in the CD report, however, used a previous version (SENES (1992)) of the AERCO$T™ model.

The use of the AERCO$T™ model in the CD is poorly explained. Tables IV.3 through IV.6 in the CD appear to be derived using the AERCO$T™ algorithms for abatement cost functions, but the tables are referenced as SENES Consultants. Similarly, the CD refers to its cost model as originated with SENES Consultants (Section IV.5.1) but that future estimates will be generated using the AERCO$T™ model developed by Environment Canada. Although it is assumed that the cost abatement functions in the SENES model and AERCO$T™ model are similar, the comparability of the two model formulations is confusing and obscure.

Because the AERCO$T™ model is a proprietary model, there was no documentation the CD or in the public domain concerning the model's functionality, validation, or underlying assumptions. Unlike the AQVM model, AERCO$T™ is not systematic, explicit and transparent. This could, of course, be due to the proprietary nature of the model - making it difficult to pinpoint the assumptions and choices made. This model uses Cost Estimating Algorithms (CEAs) for over 168 emission control technologies.

A confidentiality and non-disclosure agreement was required before any Panel member could inspect the model's documentation. While such restrictions are understandable in terms of protection of intellectual property, the lack of transparency in documenting the underlying operating features of the AERCO$T™ model is viewed as a serious weakness in the CD, and in any other reports that incorporate this proprietary model.

B. Scientific uncertainties

SENES (1996) has "ground-truthed" the cost estimating algorithms incorporated within the AERCO$T™ model by obtaining actual costs for existing facilities at which emission controls have been applied and compare these with costs calculated by AERCO$T™ for the selected sites. It is via this "ground-truthing" that +/-30% accuracy was established for the cost estimates. "Ground-truthing" is not a recognized approach to validate a model. Approaching one company to validate costs is not sufficient. According to SENES (1996), many companies in various industries refused to participate. For many companies, current or projected costs of emission controls are considered as confidential or even as a trade secret to maintain competitive advantage vis-a-vis other companies or sectors. However, it is in the best interests of firms to participate in this information gathering process if a fair assessment of emission control technology costs is to be made.

An independent validation of the AERCO$T™ model is also necessary to resolve some of the following ambiguities:

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- SENES (1995) p. s-13. "In the few cases where U.S. data had to be used, the Canadian cost was determined by using a $US to $CDN exchange rate of 1.670 in 1990." The Panel has verified with SENES that this is a typographical error. The U.S. – Cdn exchange rate in 1990 was $1.1668 (average over the year).

- SENES (1995) p. s-13: The current model (AERCO$T™) does not allow for existing technologies already in place. This is indeed a problem.

- A cost sensitivity analysis is needed to take into account various cost uncertainties. In the end, the cost estimated using the AERCO$T™ model will be subtracted from benefits estimated using the AQVM model for each year and discounted to obtain a present value.

- The Panel notes that MOE asked Environment Canada to update their Ontario PM_{10} emissions inventory for AERCO$T™, but that this update was not provided to MOE within the CD time frame ("...this is an outstanding request to them" -- see Appendix E: Response to Stakeholder Comments, p.30 top).

Regarding implementation costs, it is important to highlight that no benefits will be realized unless emissions objectives/targets are reached. The latter requires a monitoring and/or enforcement process. Voluntary initiatives are honorable but incentives mechanisms (emissions trading, environmental R&D subsidies, taxes, fines, fleet emission controls) and monitoring mechanisms are required to validate such initiatives and provide Ontarians assurances that their welfare is being considered. Consequently, the costs associated with the monitoring and/or enforcement process must also be included in the analysis.

All costs in the CD document relate to implementation of technology controls. There are some questions as to how companies choose such technologies and what incentives they will have to undertake such investments. Do they purchase the most effective pollution control technologies? Do they purchase the cheapest technologies? Do they purchase the least-cost technologies to achieve each emission reduction goal or do they take a more holistic approach and examine their total emissions inventory? In other words, how will the emission controls strategy be implemented? A list of possible implementation strategies and their associated costs/benefits should have been included in the CD or, at least, alluded to. Here the pros and cons of such implementation strategies as emissions trading, pollution taxes, voluntary controls and regulatory controls could have shed some light (and some interesting debate) on this issue.

Concerning transboundary pollution effects, the cost analysis assumes that the Province of Ontario is a self-contained airshed. This is obviously not the case, as a significant proportion of PM and PM-precursor air pollution is generated upwind and transported into Ontario, mainly from the Central United States. To the extent that emissions reductions from Ontario industries can only accomplish a partial reduction in ambient PM in Ontario, the abatement cost functions lack realism and are seriously biased towards a more optimistic prediction of pollution abatement than can actually be achieved by emissions controls within the province.

The co-benefits of recent or newly-enacted emission control programs for reducing other ambient or toxic pollution sources are not considered in the cost analysis. The proposed 30 ppm sulphur standard for gasoline, for example, would presumably reduce sources of SO_2 and sulfate as precursors to PM,

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especially secondary $PM_{2.5}$. These programs are essentially 'costless' with respect to a primary PM emission reduction program, yet their positive impact is not factored into the costs analysis. Similarly, any recent or future programs to reduce emissions of PM precursor pollutants, especially SO_x and NO_x, are likely to provide significant reductions in ambient PM levels at zero cost to the primary PM emissions control program.

On the issue of competitiveness, every company can take a different perspective on this topic. If the implementation of a clean technology makes the company more energy efficient, the cost of implementing the technology will not be as high since it will receive some payback via reduced energy costs (Porter and van der Linde (1995)). If, however, the company chooses to use end-of-pipe technologies, which have little or no cost saving features, the opposite is true. With these cost influences, companies need to consider taking a more pro-active stance with respect to environmental stewardship (Henriques and Sadorsky (1996, 1999), Schmidheiny (1992)) which, according to the CD, would suggest a commitment to clean and efficient environmental technologies.

5. Uncertainty in model formulation and predictions

A. Documentation issues

The Hagler-Bailly model integrates the health impacts and PM_{10} reduction benefits modules within an integrated Monte-Carlo simulation package using limited uncertainty analysis (hi, central, and low estimates for health impact and PM_{10} reduction benefit for each endpoint). It is a 'limited" Monte Carlo because it samples its values from the hi/med/low point estimates instead of from a continuous probability distribution function. The HB authors claim that this approach is acceptable because the hi/med/low estimates are sparse samples derived from a small number of epidemiological studies, and therefore they contain 'subjective judgments' by the modellers. Hence they cannot and should not be parameterized as a probability distribution function (PDF). This issue is not adequately discussed in the CD.

B. Scientific uncertainties

The HB and AERCO$T™ models, unlike Tracking and Analysis Framework (TAF) used by Burtraw et al. (1998), do not allow for an integrated assessment of costs and benefits of emission reductions, since they do not explore costs and benefits under a consistent set of assumptions. To assure that the benefits and costs can be explored under a consistent set of assumptions and sensitivity cases, efforts must be made to integrate these assessments and verify that all models use the same relevant indices.

In any cost-benefit study, the analyst makes many choices with regard to which valuation methodologies are employed, the fashion in which they are employed, and a host of parameters, which might affect the analysis. Examples of the latter include the discount rate, the value of human life, the rate of growth of certain economic and social variables (such as population, GDP or demand for goods such as vehicles). Consequently, two economists may perform a cost-benefit analysis and come up with very different answers. Neither one is right or wrong, as their analyses are correct based on the assumptions and choices that were made. This does not mean, however, that cost-benefit analysis is meaningless but that one should be very skeptical when a cost-benefit analysis presents a single number. The most useful way to conduct a study of this nature is to allow the treatment of the assumptions to change and see how

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the different treatments affect the results. Similarly, one can allow the values of parameters such as the discount rate and the value of a statistical life to change and see how sensitive the results are to changes in these values.

Missing, for example, is a sensitivity analysis of the discount rate. An important aspect of understanding cost-benefit analysis is establishing the time horizon of the various costs and benefits. In the CD, it was assumed that 1) it could take as long as ten or eleven years after emissions are reduced before beneficial effects are fully realized and 2) emission reductions would be realized within one to three years, depending on how long it takes to install and implement the environmental control systems. The higher the discount rate, the less important are future costs and benefits. This implies that the present value of the net benefits of a project will be critically dependent upon the choice of discount rates.

Richard Porter (1982) provides an excellent discussion of the sensitivity of the net benefits of an environmental resource to the choice of discount rates. Although there is a great deal of controversy regarding the choice of discount rates, there are essentially two basic positions. The first is that the social discount rate should be set equal to the risk-free real market rate of interest. The second is that the social discount rate should be less than the risk-free real market rate of interest. Any market rate of interest has three components. These are an inflation component, a risk component and a real interest rate. A real rate of interest is simply a market rate of interest with the inflation rate taken out. The risk premium must also be netted out of the real rate of interest before discounting. In general, the higher the risk of default on a loan, the higher the interest rate that the lender will demand in order to make the loan. Economists argue that as a society, we should ignore the risk component because society's portfolio of investments is so diversified that the risk is eliminated. To account for this uncertainty, a sensitivity analysis should be conducted to take into account the two basic positions described above. The first position is to set the discount rate equal to the risk-free real market rate of interest. The risk-free real market rate of interest can be estimated using the Canadian 3-month Treasury bill (T-bill) as the risk-free market rate of interest and subtracting inflation. A mean T-bill rate of approximately 4% was obtained using data from January 1990 to November 1998. This is, in fact, the rate used in the CD. To account for the second position, a rate below 4% should be set (2 or 3% for example).

Regarding scenario assumptions in the HB and AERCO$T™ models, the only control scenario presented in the CD for the PM emissions reduction program is the 'proportional rollback' scenario. Both the HB model and AERCO$T™ model depend on this proportional rollback scenario, which assumes that all industrial firms, sources, and sectors in Ontario will be required to reduce PM emissions by an equivalent proportion, whose magnitude depends on the aggregate emissions reduction goal required to achieve a specified ambient PM concentration. An alternative scenario, the 'peak shaving' scenario is briefly discussed in the CD but is not analyzed quantitatively in the HB or AERCO$T™ models. This is an important weakness, because the peak shaving strategy is based on identifying and mitigating those emissions sources which have the greatest impact on daily or weekly ambient PM excursions (peaks). Considering that the monetizing of health benefits in the HB model is predominantly influenced by mortality effects from acute PM exposure, the use of an peak exposure reduction scenario is highly relevant. The peak shaving scenario also promises to provide a locality-specific means of reducing peak emissions in heavily populated urban centres. This scenario would serve to inform decision-making with respect to costs of control for PM emissions in urban Air Quality Management Areas (AQMA) in Ontario, which are not directly addressed in the proportional rollback scenario.

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Chapter 2

Characterization of the Levels and Sources of Uncertainty Arising from Information Gaps

Politicians and regulators who work with risk assessors often express regret over the absence of "one-armed scientists" willing to provide unambivalent technical answers to risk decision questions. Instead, most risk assessment findings are carefully couched in terms of the strengths and weaknesses of the evidence of risk, uncertainties about the degree of risk, and guarded statements about the likely effectiveness of various remedies. The cautious 'on one hand this, on the other hand that' approach, while frustrating in its complexity, permits regulatory and political decision makers to evaluate various options for controlling risks without being restricted to a predetermined risk estimate and a single control option. The ultimate decision of how to deal with uncertainty must be treated as risk management decision.

> *Science cannot always provide the certainty we would like to have to make reasoned risk management decisions. But it is unacceptable not to convey to the responsible officials what the range of uncertainty is. The decision whether and how to deal with uncertainty is a risk management decision, and must be made by the responsible regulatory official. If some of the relevant information, or the uncertainty is not disclosed to the decision maker and to the public, the policy making process will be compromised. The real risk management decision will not be made by the regulatory officials but instead by those involved in the risk assessment process who determine which data to use, which of several scientifically valid models to employ, and which information to reveal.*
>
> *OMB, 1986 (reproduced in Barnard, 1991)*

The Panel considers that a comprehensive and systematic quantification of the impact of gaps and uncertainties on strategic options was not feasible at the present state of knowledge. The experience of the EPA Clean Air Science Advisory Committee (CASAC) with respect to characterization of uncertainties for the EPA $PM_{10/2.5}$ National Ambient Air Quality Standard (NAAQS) is illustrative of this point:

> *In recommending that the (EPA) staff carry out a risk assessment, it was the expectation of CASAC that the risk assessments would narrow the diversity of opinion by evaluating how all of the uncertainties propagate through the entire model. However, not all of the uncertainties could be included and the combined effect of all of them could not be examined.*
>
> *CASAC (1996b), closure document 13-6-96*

Consequently, the Panel has elected to produce a summary framework for characterizing the potential impact of information gaps and uncertainties on policy formulation for the control of $PM_{10/2.5}$ in Ontario. The framework is based on frequently cited scheme for characterizing the level

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of uncertainty in a semi-quantitative manner, first proposed by Wynne in 1992. This scheme ranks the level of uncertainty according to the criteria described in TABLE 2-1.

TABLE 2-1: Levels of Uncertainty (after Mitchell, 1995; Wynne, 1992)

Risk	Know the odds.
Uncertainty	Do not know the odds. May know the key variables and their parameters.
Ignorance	Do not know what we should know. Do not even know what questions we should be asking.
Indeterminacy	Causal chains or networks are open. Understanding not possible.

The least degree of uncertainty is denoted as 'Risk', which occurs when the degree of scientific understanding and empirical information is sufficiently high to permit the accurate prediction of adverse environmental consequences with a high degree of confidence. The residual uncertainty represented by "risk" at this level of information reflects the fundamental unpredictability of chance events, arising from natural variability in exposure to hazardous agents and the variable susceptibility of different individuals within a population. This type of 'risk' uncertainty therefore cannot be reduced by further data collection or research programs.

The next degree of uncertainty is termed 'Uncertainty'. This level of uncertainty occurs when partial scientific information is available to understand and predict a risk, but the information is incomplete or contradictory. A better understanding of the underlying scientific principles that explain the risk is required, along with more extensive and accurate observational data describing the nature and extent of the risk. Uncertainty at this level can be readily reduced through a concerted program of scientific research directed towards those issues with the greatest influence on the decision-making process for control of the hazard.

The third level of uncertainty is termed 'Ignorance'. This level characteristically reflects a situation where there is fragmentary information about a risk, and little or no understanding of the scientific principles that determine risk. However, there may be enough information available to identify key questions to be addressed by further research. Problems that are amenable to scientific analysis can be identified and prioritized, including questions that have been overlooked or poorly formulated in existing studies.

Finally, the greatest level of uncertainty is regarded as 'Indeterminacy'. At this level, it is basically impossible to address a problem scientifically, either because the problem is too complex a task for current investigational techniques, or because the question is not accessible to scientific enquiry. The latter category often includes questions of societal values, such as the "acceptability" of risk, or the "value of a life". Some scientific questions that are poorly conceived or badly formulated

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fall into this class as well, such as the controversy over the use of low-dose linearity models for carcinogenic chemicals.

A second scheme that the Panel has adopted for characterizing uncertainty represents an adaptation of the uncertainty framework developed by Finkel (1990). A slightly modified form of this framework is provided in TABLE 2-2. The sources of uncertainty approach can be used to divide uncertainty into several major categories.

Parameter uncertainty is attributable both to statistical uncertainty arising in the estimation of model parameters due to measurement error and sampling error, or alternatively from systematic errors arising from biased sampling or flawed experimental design.

Model uncertainty reflects the limited ability of mathematical models to accurately represent the real world. Misspecification of model form and the functional relationships between critical variables often is the result of lack of sufficient theoretical knowledge to adequately define the structural and operational characteristics of the model.

Decision-rule uncertainty takes the form of imprecise or inappropriate operational definitions for desired outcome criteria, value parameters, and decision variables. These include the selection of particular types of summary statistics for outcome measures (e.g. lifetime mortality risk versus annual mortality risk), and the choice of variables that express subjective value judgments in the form of utility functions (e.g. the money value attributed to loss of life).

Integration uncertainty reflects the problem of combining disparate scientific and economic models, commonly based on fundamental assumptions and formulas that are not always in agreement with each other. The meshing together of models developed for differing purposes in different localities often requires a close examination of the generalizability of the model, as well as its scope and operating principles. Ideally, a decision-making model should be "integrated" so that all of the scientific and economic questions are addressed consistently and within a seamless framework. The current development of the TAF model for analyzing the risk-cost-benefit equations for $PM_{10/2.5}$ and other smog constituents represents such an integrative model.

In addition, TABLE 2-2 provides a set of uncertainty subtypes for each of the four major sources of uncertainty. For parameter, model, and decision-rule uncertainty, these uncertainty subtypes have been taken directly from Finkel (1990).

The Panel itself has developed several specific subtypes for integration uncertainty, as the model integration issues regarding PM are somewhat more specialized. Finally, a number of possible examples of uncertainty sources pertaining specifically to PM and air quality are presented for illustrative purposes in the rightmost column of TABLE 2-2. This list does not constitute a comprehensive or detailed listing of all uncertainty issues, but rather is intended to provide a representative sample of issues that the Panel has identified, according to the particular uncertainty subtype that the issue exemplifies.

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TABLE 2-2: Sources of Uncertainty and Uncertainty Subtypes in Environmental Decision-making (after Finkel 1990)

Sources	subtypes of sources	possible examples
parameter uncertainty (P)		
	P1. measurement errors	* inaccurate ambient PM monitoring * ambient vs. individual exposure * incomplete air monitoring grid
	P2. random errors	* small sample size * inadequate statistical power
	P3. systematic errors	* inadequate adjustment for smoking status in sample cohort * inadequate adjustment for weather-related effects
model uncertainty (M)		
	M1. surrogate variables	* PM_{10} as indicator for $PM_{2.5}$
	M2. excluded variables	* co-pollutants as confounding factor
	M3. abnormal conditions	* Gaussian plume dispersion versus fumigation dispersion
	M4. incorrect model form	* linear non-threshold vs. nonlinear dose-response model
decision-rule uncertainty (D)		
	D1. measure to describe risk	* mortality vs. morbidity endpoints * acute versus chronic health effects
	D2. summary statistic to characterize risk	* mortality rates versus reduced life expectancy
	D3. defining "acceptable" risk	* use of cost-benefit analysis method
	D4. utility function for summary measure	* monetizing for "value of a life" (WTP)
	D5. aggregating of individual utilities	* proportional linear rollback assumption vs. 'peak shaving'
	D6. immediate versus delayed consequences	* discount rate for costs and benefits of emissions controls
integration uncertainty (I)		
	I1. generalizability	* relevance of US-based air models to Canada climatic conditions
	I2. incompatible or incomplete model formulation	* AERCO$T™ model vs. HB model * point estimate risk models vs. probabilistic risk models
	I3. differences in model inputs and assumptions	* 1990 vs. 1995 Ontario emissions inventories
	I4. defining model scope	* transboundary transport of PM & PM precursors from US sources
	I5. synergism and spill-over effects not included in model	* effects of changes in gaseous smog constituents (SO_x, NO_x, ozone)

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As a final step in characterizing the major levels and sources of uncertainty regarding the PM problem, the Panel has devised a summary TABLE 2-3. The first column of TABLE 2-3 lists the major information gaps that the Panel members have previously identified in Chapter 1. For each information gap, the adjacent columns of the table provide a semi-quantitative ranking of the relative levels of uncertainty according to the Wynne 1992 framework (see TABLE 2-1), and the representative subtypes of uncertainty sources according the Finkel (1990) typology (see TABLE 2-2). The alphanumeric codes within the columns are used for two purposes: (1) the column position of the alphanumeric items denotes the level of uncertainty (in many instances a range of levels) for each identified information gap and (2) each individual alphanumeric item describes the relevant subtype of uncertainty.

In this manner, both the level and sources of uncertainty can be summarized together in one table. TABLE 2-3 is not meant to be strictly analytical, but rather reflects the expert judgement of the individual Panel members concerning the uncertainty issues that are related to specific information gaps within their particular area of expertise. To the extent that several information gaps overlap between different disciplinary areas, there may be some duplication in uncertainty items, but this does not detract from the overall intent of the summary table.

All of the entries for TABLE 2-3 have been derived using the relevant textual comments of the Panel members. These comments were embedded electronically within the computer-format version of TABLE 2-3 to provide assistance to Panel members in assembling and reviewing TABLE 2-3 entries. However, due to their length and complexity, the textual comments used to assemble TABLE 2-3 are not included in the Final Report.

A limited number of the major questions were considered by the Panel as having minimal scientific uncertainty, and these are denoted in TABLE 2-3 by the entry 'yes' appearing in the 'risk' column. Question 2.1, for example, is viewed as having minimal residual scientific uncertainty because the control technologies for reducing emissions of PM and PM precursors are currently available as scientifically well established technologies. However, the long-term engineering efficiencies and capital/operating costs of these technologies cannot be known in advance with great precision, due to the unpredictable operating characteristics of technological control solutions in complex industrial settings. The residual risk of inefficient technology or excessively costly performance can be characterized, however, by using efficiency prediction models derived from combustion engineering principles (Frey & Rubin, 1991). Such probabilistic models may serve to further reduce risk of excessive costs by identifying the most critical operational parameters for efficient application of combustion technology.

The second table entry where uncertainty is minimized to the level of 'risk' is for Question 4.1, regarding a possible causal association between PM and cardiopulmonary morbidity and mortality. In this instance, there is minimal uncertainty about elevated PM exposure being statistically associated with adverse health effects, so that a series of mortality and morbidity risk coefficients can be assigned to various health outcomes for the purposes of statistical modelling. However, in this case the entry 'yes' for 'risk' is restricted only to the most general formulation of causality – i.e., that PM is consistently associated with an elevated risk of adverse health effects within a complex mixture of smog constituents. Other causality issues pertaining to co-pollutants, smoking status, ambient versus individual exposure, etc. remain to be characterized, and these items are placed in the 'uncertainty' and 'ignorance' columns, using the codes for the various sources and subtypes of uncertainty as previously described in TABLE 2-2.

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TABLE 2-3: Summary of the Level and Type of Uncertainties for PM Control in Ontario (see Table 2.2 for definitions)

Key Questions Identified to Assess InformationGaps in 5 Main Theme Areas: 1. Atmospheric Science 2. Control Technologies 3. Exposure Assessment 4. Health Effects 5. Cost Benefit Analysis	Risk	Uncertainty	Ignorance	Indeterm-inacy
1.1. Is there sufficient knowledge of the spatial and temporal variation of the concentrations of $PM_{10}/PM_{2.5}$ for use in health studies and development of control strategies?		P1, P2, P3, M3, I1	M1	
1.2. To what extent can human exposures be determined from the existing ambient concentration data?		P1	M1	
1.3. Are background levels of PM sufficiently well defined for meaningful interpretation of other data?		P1	I1	
1.4. Can ambient PM be apportioned to various sources?		P1, P3, I3	M4, I1, I2	
1.5. Is the relationship between emissions and sources sufficiently well understood to relate changes in emissions to changes in ambient concentration?		M1, M3	M4, I5	M2, I4
2.1. Are there control technologies capable of reducing the emissions of PM and PM precursor gases?	yes			
2.2. Can new control technologies be instituted in Ontario?		I1, M1, M3	D6	
2.3. Number of pollutants that require control and multiple control strategies—issues of the integration of control technologies		I3	I5	I4
3.1. particle sizes (PM_{10} and $PM_{2.5}$) and chemical speciation (sulphates, nitrates, metals, etc.)		M2	I5	
3.2. gaseous co-pollutants (SO_x, NO_x, ozone, CO) contributing to mortality and morbidity		M2		
3.3. ambient exposure from central monitoring stations versus personal exposure of individuals?		P1	M1	
3.4. transboundary pollution from the central United States affecting ambient PM levels in Ontario?		M2, M3		I4
3.5. particle size and speciation factors affecting deposition of particles in regions of the lung		P2, P3	M1, M4	I1
4.1. causal relationship between PM exposure andcardiopulmonary mortality/morbidity?	yes	P1, P3, M1, M2, M4	M3	
4.2. does mortality reflect the advancement of death by only a few days (harvesting effect)?		M3, D2, D4		D3
4.3. PM size component (PM_{10} $PM_{2.5}$) most directly involved in health effects		P1, M1,	M2	
4.4. dose-response relationship between ambient concentrations of $PM_{10-2.5}$ and health effects		P2, P3 I1	M4, D1	I1
4.5. does the risk characterization entail a strictly linear nonthreshold dose-response model?		D2	M4	
5.1. linear nonthreshold dose-response function as an exclusive basis for estimating health benefits			M4	
5.2. monetizing health benefits for reductions in mortality risk and morbidity risk		P3		D3
5.3. exclusion of non-health risks and benefits from the cost-benefit analysis				I4
5.4. projected costs of control to industry in Ontario from targeted reductions in air emissions		P1, P3, M4	D6, I5	I4
5.5. cost-benefit model uncertainties in model variables, valuations, and assumptions		I3	I2	I1

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Under Question 4.1, for example, the entry P1 (Parameter uncertainty subtype-1 - Measurement errors) denotes the following concern identified by the Panel: *"possible exposure classification errors due to ambient monitoring data being used for individual exposure".* Similarly, the entry P3 (Parameter uncertainty, sub-type-3 – Systematic errors) reflects the Panel's concern about: *"possible inadequate adjustment for smoking status in sample cohort.".* Other entries in the same row (M1, M2, M4) identify various types of modelling uncertainty., The entry M1, for example, denotes the following Panel comment: *"PM10 as an indictor for PM2.5 — which is actually the toxic agent? — many studies rely on PM10 or TSP or visibility reduction as a surrogate measure for PM2.5."* The entry M2 denotes: *"gaseous co-pollutants as confounding factors for PM-associated morbidity and mortality".* The entry M4 denotes: *"model form – why do some models give unstable results for multiple regression? – why are bivariate (PM and one gas) regressions required? – This problem has moved from "ignorance" to "uncertainty" due to the recent HEI study results".*

For Question 4.1, there is a single entry placed in the 'ignorance' column, M3: *"abnormal conditions – does PM affect health adults, or does it selectively affect 'high-risk groups", such as children, the elderly, those with COPD, asthma, etc.?"* Although this issue is currently being addressed in more recent epidemiological studies, relevant data was not presented in the CD for the Panel to consider; thus the Panel viewed its level of knowledge as 'ignorance'.

Finally, several questions were ranked as falling partly or completely in the column for "indeterminacy". There were diverse reasons for some questions being ranked at this extreme level of uncertainty. Question 5.3, for example, is placed in the 'indeterminacy' column as entry I4 (Integration Uncertainty, subtype 4 – Defining Model Scope), because it reflects the Panel's concern about the lack of inclusion of non-health risks and benefits in the cost-benefit analysis. Because such valuation may be outside of the scope of the CD, the question is indeterminate – it depends on the regulatory mandate of the MOE under the relevant legislation. Similarly, for Question 3.4, concerning transboundary air pollution, the indeterminacy is political -- whether or not the U.S. Environmental Protection Agency (EPA) will be able in the foreseeable future to enact more stringent NAAQS standards for PM 10 and PM2.5. Such predictions are clearly beyond the powers of scientific analysis.

However, some of the indeterminacy issues were based on societal value-choice issues. Question 4.2, for example, addresses the mortality advancement (harvesting effect) problem. Part of the question can be addressed in terms of explicit modelling and decision criteria (M3, D2, D4). The indeterminacy resides with D3 (Decision-rule Uncertainty, subtype 3 – Defining "Acceptable" Risk). If societal values dictate that risk of premature death by a few days is formally equivalent to risk of premature death by many years (i.e., death in sick elderly is equally bad as death in healthy children) then an absolute model of life valuation should be applied. Alternatively, if premature deaths are discounted according to remaining life expectancy, then children are more valued than the elderly. It is obvious that this type of ethical indeterminacy cannot be addressed by scientific means, and will instead rely on the wording of the relevant legislation, the interpretation accorded by the regulatory agencies, or by judicial rulings.

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Chapter 3

Analysis of Strategic Options

I. Fundamental Considerations

The third major question addressed to the Panel in its Terms of Reference was to assess the impact of knowledge gaps and uncertainties on the seven Strategic Options for ambient PM control, as described in the MOE Strategic Options document (SOD). Although the Strategic Options document constitutes a distinct report from the CD report, its development was undertaken with most or all of the CD information at hand. The seven Strategic Options presumably represent alternative approaches to deriving an effective control strategy for ambient PM in light of the existing gaps and uncertainties identified in the CD.

As a prefatory note, the Panel was aware that none of the proposed seven Strategic Options is capable of ensuring complete safety from harmful health effects. Absolute assurance of safe levels of PM exposure is impossible to achieve, because a toxicity threshold for PM has not yet been identified, and indeed may not exist. Therefore, policy approaches based on the concept of "no harmful effects" with inclusion of "an adequate margin of safety" -- which is the definition of safety under which U.S. EPA must act within the legislated mandate of the Clean Air Act -- is not currently feasible for selecting MOE strategic options for the control of exposure to ambient $PM_{10/2.5}$.

Instead, the health risks of $PM_{10/2.5}$ should be minimized to the maximum extent possible, given limitations in scientific knowledge, control technology, and costs of control that currently exist, or are likely to exist in the foreseeable future. The Panel's conceptual foundation for evaluating the seven Strategic Options is based fundamentally on adherence to the Precautionary Principle as enunciated by Environment Canada and other Canadian regulatory bodies (Environment Canada, 1996):

- the primary objective is minimization of harm to human health;
- appropriate remedial and preventive actions shall not be postponed or unduly delayed by the presence of uncertainty;
- evaluation of evidence shall be based on adherence to sound science; and
- decision-making shall include a careful consideration of the cost-effectiveness of any proposed course of action.

This set of principles can be referred to as the "utilitarian" precautionary principle -- in distinction to the "ecocentric" precautionary principle which seeks to downplay the need for scientific evidence and cost-effectiveness (VanderZwaag, 1994). In the opinion of the Panel, the adjective "utilitarian" should not be treated in a pejorative sense, but rather should reflect the need to

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ensure public safety in accordance with the principles of sustainable economic development within Canada.

A 1993 Comprehensive Air Quality Management Framework for Canada, agreed to by federal, provincial and territorial governments through the National Air Issues Co-ordinating Committee (NAICC), includes the precautionary principle among its list of principles of cooperation. The Framework provides that: *"Preventive and corrective actions will be based on the precautionary principle, sound science, and consistency with nationally acceptable data and assumptions."*

II. Option Analysis

The option analysis phase of environmental decision-making usually includes two basic steps. The first step is typically termed "Identification of Options", while the second is termed "Selection of Option(s)". The SOD report has provided a set of seven Strategic Options which delineate some possible IP/RP strategies for controlling ambient PM pollution in Ontario. These options are presented in the SOD, both as a descriptive listing of options (SOD Section 4 "Strategic Options") and as an annotated summary table (SOD Table 1) "Possible IP/RP Strategic Options and Associated Considerations". The Panel members extensively discussed the contents of SOD Table 1, and most of the comments of the Panel members were addressed to the information provided in this table. The Panel then addressed some basic concerns regarding the criteria for selecting one of the seven Strategic Options.

First, the Panel noted that the process by which the seven Strategic Options were identified and delineated is entirely obscure. Although the SOD enunciates several "guiding principles for developing an IP/RP strategy" (SOD p.2), the relationship of these principles to the actual strategic options is not explained. Similarly, a list of six 'additional considerations' (SOD p.2-3) is presented in the SOD, but there is no apparent connection between these considerations and the Strategic Options. Thus the Strategic Options appear to be products of creative thinking within the MOE staff and/or the Smog Plan Steering Committee. While such efforts are themselves praiseworthy, it was very difficult for the Panel to weigh the options in any consistent and objective manner, especially since the options are presented in summary format without extensive explanation.

Second, the Panel noted that the seven Strategic Options delineated in SOD do not constitute a comprehensive and mutually exclusive set of options. There are, in fact, many other possible strategic options that could also be delineated as various permutations of the proposed control measures contained within the seven Strategic Options. The Panel therefore concluded that the seven Strategic Options represent a limited subset of all possible options -- those listed could be considered as prototypes of many other possible strategic options.

Third, the Panel observed that the various control measures described in each of the seven Strategic Options were based on several distinct types of control criteria. Several options proposed enforcement of revised AAQC levels for ambient PM while others presented emission control targets for PM sources and gaseous precursors. In some options, implementation time lines of varying duration were cited as examples. Some focussed exclusively on uniform AAQC levels while others suggested adoption of different AAQC levels for Air Quality Management

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areas (AQMA). The Panel also noted the potential for devising new strategic options, using various "mix and match" combinations of these diverse criteria.

Finally, the Panel was unanimous that the present uncertainties cannot be used as a basis for postponing action. The Panel strongly supports the statement in the SOD which asserts that:

> *A better understanding of the science would help refine, optimize, and refine (sic) a strategy; however, it should not be used as a reason for postponing actions to deal with the issue.*
>
> *SOD Section 5.*

Based on these all of these considerations, the Panel felt whatever strategic option was ultimately selected, a fully "parameterized" version of all the seven Strategic Options would be necessary for informed decision-making. This means that all control measures to be implemented within a given option would need to be specifically defined and would be consistent with respect to the other possible options for the purposes of comparison and selection.

The Panel therefore elected to undertake an analysis of the seven Strategic Options (and their possible permutations), by decomposing the various control measures into their respective categories according to the type of control objective that the measure entailed, and defining each more fully.

III. Decomposition of Options into Specific Components

In order to fully characterize each of the seven Strategic Options, the options must be decomposed "parametrically" into various categories representing the underlying control objective for air quality, the control measure intended to achieve the objective, and the decision criteria for defining the fulfillment of the objective.

The categories for defining objectives were identified by the Panel according to six major criteria:

1. ambient air concentration level
2. particle size
3. form of attainment
4. geographic averaging
5. implementation time
6. emissions reduction strategies

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1. ambient air concentration level

Both the CD and the SOD propose three possible ambient air concentration levels for specifying a revised AAQC:

- 60 ug/m^3 PM_{10} (10 above interim AAQC)
- 50 ug/m^3 PM_{10} Ontario interim AAQC for PM_{10}
- 40 ug/m^3 PM_{10} (10 below interim AAQC)

All three of these levels are included in the quantitative modelling for health impact analysis, health benefits analysis, and cost-of-control analysis presented in the CD. To the extent that the CD models might provide valid and accurate estimates of health risks, health benefits, and control costs, the CD may be informative concerning those Strategic Options that include proposed AAQC levels (e.g. 60, 50, or 40 ug/m^3 PM_{10}).

In addition, the Panel noted that the proposed AAQC levels are only meaningful in comparison with the present AAQC for Ontario (50 ug/m^3) and the corresponding NAAQS for the U.S. EPA (150 ug/m^3). The Ontario value is important because it represents the *'status quo'* scenario for no action. Even if no action is to be treated as an undesirable option, it should be included within the possible Strategic Options to provide a 'point of departure' for the other more rigourous control options to be considered (i.e. it also serves as the baseline scenario for the cost-benefit analysis).

The current U.S. EPA NAAQS level for PM_{10} was effectively defined as Option 7 in the SOD. This air quality benchmark is important because it illustrates the large differences in air quality criteria that currently exist between Ontario and the United States. Considering that the proposed EPA PM_{10} NAAQS are being reviewed in the context of implementation in recent months, this issue deserves greater consideration in future deliberations.

2. particle size

The SOD Strategic Options include several suggested approaches for dealing with uncertainties surrounding the appropriate definition of the PM particle size to be controlled. The greatest source of uncertainty is the question of whether $PM_{2.5}$ (fine particulate; respirable particulate) represents the particle size fraction most directly associated with adverse health effects, especially cardiopulmonary mortality effects.

This issue is important with respect to a revised AAQC standard, because MOE estimates that *"...the percentage (emissions) reduction necessary to attain the specified $PM_{2.5}$ goal is usually higher than that of the PM_{10} goal. Therefore, meeting the $PM_{2.5}$ goal will likely meet the corresponding PM_{10} goal."* Although this statement is presented in the context of locality-specific PM emissions (for Hamilton, Toronto, Windsor, Ottawa), it is probably true for province-wide AAQC as well, considering that $PM_{2.5}$ is generally more widely dispersed than PM_{10}.

Unfortunately, the CD is inconsistent with respect to the possible pathogenic role of $PM_{2.5}$. On the one hand, the CD asserts that:

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> ***These preliminary estimates indicate that over 90% of premature mortalities and hospital emissions are due to $PM_{2.5}$"*** (Section III.5.2.2), ... ***As with the present study and previous work carried out by the Ministry of the Environment, reductions of fine particulate ($PM_{2.5}$ or smaller) will yield the vast majority of reduced mortality and morbidity health effects.*** (Section IV.4 p.IV.8 para. 2).

However, the reference cited (Anderson, 1997) in support of this statement is somewhat more ambiguous. Anderson describes that 19/21 EPA CASAC Panel members supported establishing new $PM_{2.5}$ NAAQS standard, but that no consensus could be reached on the level, time-averaging, and form of attainment for $PM_{2.5}$ ambient air quality standard (CASAC, 1996b). The EPA CASAC panel, while agreeing that $PM_{2.5}$ was important (CASAC, 1996b), chose also to recommend the retention of the present NAAQS for PM_{10} (at 150 ug/m^3). The basis of this recommendation was the belief by many CASAC members that the coarse particulate fraction of PM_{10} ($PM_{10-2.5}$) was likely responsible for at least some acute health effects, such as asthma (Anderson 1997 p.5).

The Panel has noted the sparse amount of Ontario-specific ambient monitoring measurements currently available for $PM_{2.5}$ in Ontario. With the exception of the NAPS $PM_{2.5}$ monitoring in four large urban centres, very little useful information exists. In addition, there are only a few epidemiological studies that have used $PM_{2.5}$ as a primary metric. The findings of these suggests that ambient $PM_{2.5}$ is an important exposure metric, but much more extensive and systematic measurements are desired for research and enforcement of a $PM_{2.5}$ AAQC standard.

3. form of attainment

The form of attainment for the PM AAQC is not adequately examined in the CD or the SOD options, in contrast to the United States, where the EPA form for defining attainment of the NAAQS has been under extensive review (U.S. Federal Register, 1997). The MOE and the U.S. EPA currently use similar attainment measures for determining exceedences from the ambient air quality criteria, i.e., the 3rd or 4th maximum observed 24-hour concentration over one year (EPA three years). However, this definition of the 'representative maximum' concentration (CD Section III.5.2) is statistically unstable, because the annual number of daily exceedences detected is proportional to the frequency of sampling (lower sampling frequency entails fewer detected exceedences). A more 'robust' form of the representative maximum for attainment would be a specified percentile (e.g. 98th percentile) of the sampled ambient air concentration levels.

A more fundamental issue under form of attainment is the basic methodology used to determine attainment. The CD makes an extensive argument on behalf of a broad-based emissions reduction program:

> *Thus it appears from this analysis, that focusing PM reductions strategies on 'peak' concentrations will not yield the most health benefits. Rather these data points in the direction of broad-based strategies whose aim is to reduce the whole distribution of PM levels in general.*
>
> *(CD Section III.5.2 p. III.5-26-27)*

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Indeed, the entire cost-benefit analysis presented in the CD is predicated on the broad-based reduction approach. Taken at face value, the HB cost-benefit model suggests that a short-term (24-hour) exceedence-based approach to defining AAQC levels might be relatively ineffective in reducing chronic health effects. The 24-hour standard would directly address only peak values that influence acute health effects over the short term. Moreover, a short-term exceedence approach would directly apply only if 'above-threshold' values were acutely pathogenic but 'sub-threshold' values were not. The short-term exceedence concept cannot be made operational if there is no definable threshold, or if the population threshold is broadly distributed due to differences in individual susceptibility. Conversely, a time-weighted-average (TWA) long-term exposure standard would be valid if all PM exposure levels were thought to be pathogenic in direct proportion to time-averaged ambient concentration levels over a defined period. Hence, the natural alternative to the exceedence approach is a time-weighted-average exposure measure, usually expressed as an annual maximum TWA exposure level. The U.S. EPA PM Staff Paper (U.S. EPA, 1996) supports an annual NAAQS standard for PM, while Ontario does not.

> *..., the aggregate annualized risk will be a function of the concentrations across a wide portion of the upper end of the $PM_{2.5}$ air quality distribution. Since reducing high concentration days can provide a greater microgram reduction in $PM_{2.5}$ annual average mass for a lesser percentage reduction in air quality, an annual standard will still favor reducing high concentration values. In contrast to the 24-hr standard, however, an annual standard is less likely to allow areas whose air quality concentrations are substantially above those necessary for attainment to reduce concentrations in a fashion that might not result in meaningful risk reduction (e.g., by reducing just a few high peak values). In so doing, an annual controlling standard might be expected to lead to less variation in the risk reduced in different geographic areas having similar initial air quality that reduce $PM_{2.5}$ concentrations to attain a set of PM alternative standards (U.S. EPA, 1996, Appendix F, p. F6).*
>
> *Further, in selecting specific levels for $PM_{2.5}$ standards, staff recommends that the Administrator consider the joint protection afforded by both the 24-hour and annual standards. The recommended approach is to view an annual $PM_{2.5}$ standard as the primary target for control programs designed to effectively lower the entire distribution of $PM_{2.5}$ concentrations, with a corresponding 24-hour $PM_{2.5}$ standard set so as to protect against the occurrence of peak 24-hour concentrations that would likely not be controlled by areas attaining such a new annual $PM_{2.5}$ standard (U.S. EPA, 1996, vii-48).*

The SOD, in contrast, does not propose or discuss long-term or annual exposure measures.

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4. geographic averaging

The CD and SOD do not adequately describe or address the problem of defining a suitable unit of measure for geographic averaging of attainment/exceedence levels. Based on the existing AQVM baseline data for PM_{10} concentrations, the Panel assumes that the geographical unit of measure for ambient monitoring would be at the level of census subdivisions within Ontario, or other geographic divisions of similar size resolution. This issue is important because a regional sampling area tends to dampen out local exceedences ('hot spots') because the ambient PM concentrations for all monitors are averaged over the predefined geographic attainment area. The averaging effect is greater as the size of the monitoring area increases.

This issue has the greatest impact in highly industrialized urban localities with large population of exposed individuals. The spatial resolution required to account adequately for short-term variations in ambient PM levels is likely to be much smaller than for rural or semi-rural areas. This question is reflected further in the CD and SOD, concerning the analysis on "community-specific" emission reduction scenarios (CD Section III.5.4.2 p. III.5-38-43). The main impact of these community-specific scenarios pertains to the question of whether there should be a uniform province-wide AAQC, as opposed to different or deferred AAQC levels for IP/RP Air Quality Management Areas (AQMAs).

In addition, the Panel has noted that there are significant distributional and equity issues associated with the development of community-specific AAQC levels for the AQMAs. The CD lacks any discussion of the socio-economic issues regarding geographic areas that might be permitted to incur more air pollution, with the attendant risks of poorer health, as trade-off for potential economic benefits.

5. implementation time

Several of the Strategic Options include the specification of sequential phased-in implementation time frames for various types of AAQC, for example, deferral of $PM_{2.5}$ AAQC until a later date than the PM_{10} AAQC. No explicit rationale is provided in the SOD to explain the length of any of the time frame examples presented within the Strategic Options.

The Panel appreciates the difficulty in providing a rigourous explanation for the implementation time frames presented in the SOD. These time frames reflect the various degrees of uncertainty pertaining to critical issues that are not yet adequately resolved -- PM levels, PM_{10} vs. $PM_{2.5}$, etc. -- and it is recognized that the uncertainties themselves are difficult to quantify.

Nonetheless, the Panel believes that it is essential to define at least a default set of implementation time criteria for further consideration by decision-makers. Based on the experience in other industrialized jurisdictions -- most notably Germany -- several members of the Panel suggested that the following implementation time lines should be considered as possible implementation benchmarks for the purposes of defining time lines within the seven Strategic Options:

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- a default six-year time period for "short-term" implementation of new emission controls, reflecting the time required for capital investment to modify (retrofit) pollution controls in existing installations, and

- a 12-year time period for "long-term" implementation of new emissions controls -- reflecting the time required to amortize existing capital investments while preparing to construct new installations designed to meet revised emissions standards.

Such implementation benchmarks might be useful as a framework for developing strategic options with more tightly defined time frames than those discussed in the current SOD.

6. emission reduction strategies

Several of the seven Strategic Options focus directly on specific PM emissions control targets, in place of or in addition to AAQC criteria. The relationship between the proposed AAQC levels and the absolute emissions targets is not made clear or explicit in the SOD. The potential impact of absolute emissions targets (e.g. 10% reduction in PM_{10} emissions) on health effects or ambient air quality is not described or analyzed either in the CD or the SOD. However, specific targets for reducing primary $PM_{10/2.5}$ emissions are presented in the CD with respect to the modelled AAQC levels -- there is a specific target of 19, 34, and 53 percent reduction in 'aggregate anthropogenic emissions' reductions corresponding to the 60, 50, and 40 ug/m^3 AAQC respectively (CD Section IV.4 p.IV.9).

Much of the apparent discontinuity between the AAQC targets and the emissions reductions targets reflects four major sources of uncertainty:

(1) the effects in Ontario of transboundary air pollution from the United States,

(2) the effectiveness of primary PM_{10} emissions reductions on attainment of the proposed PM_{10} AAQC levels,

(3) the effect of precursor gaseous pollutant reductions on the ambient levels of secondary $PM_{2.5}$, and

(4) the questionable effectiveness of PM_{10} emissions reductions on $PM_{2.5}$ ambient air concentrations.

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IV. Analysis of Strategic Options:

The seven Strategic Options listed in the SOD can be briefly summarized as follows (SOD Section 4):

1. *Interim AAQC of 50 ug/m^3 with at least 10% reduction in emissions*

2. *AAQC with interim and long-term target levels/dates*

3. *Long-term AAQC and interim target levels or reduction percentages*

4. *Different AAQC for AQMAs*

5. *Different implementation dates for AQMAs (same AAQC across Ontario)*

6. *AAQC for PM_{10} with $PM_{2.5}$ to follow*

7. *Harmonize with US EPA standards for PM_{10} and $PM_{2.5}$*

A more extensive description of the seven Strategic Options and their associated decision criteria is presented in SOD Table 1 "Possible IP/RP Strategic Options and Associated Considerations" (see Appendix A).

1. Characterization of Nonviable Options:

The first question concerning the impact of uncertainties on the Strategic Options is whether the CD contains enough relevant information to evaluate a specified option. In the Panel's view, the current version of the CD does not adequately inform several SOD options -- specifically Strategic Options 4, 5, or 7.

The information contained in the CD is not directly relevant to the evaluation of Option 7, because this option is based entirely on the criterion of harmonization with U.S. EPA National Ambient Air Quality Standards (NAAQS) for PM_{10} and $PM_{2.5}$.[4]

Since the criterion is based solely on harmonization with an existing standard, and not on the estimated magnitude of PM health impacts or on cost-benefit criteria, the CD cannot inform this option. However, the Panel recognizes that the scientific and technical information presented in CD clearly indicates that existing U.S. EPA NAAQS levels for PM_{10} are NOT consistent with adequate assurance of health in populations exposed to this level of ambient PM_{10}. Hence, the CD provides a compelling argument for rejecting Option 7 as a feasible future strategy for managing PM-related air pollution in Ontario.

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[4] Note: the proposed U.S. EPA NAAQS for $PM_{2.5}$ has been recently overturned in the U.S. District Court, and is unlikely to be promulgated in the near future (U. S. Court of Appeals, 1999).

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Moreover, the SOD clearly identifies the issue of transboundary air pollution from PM generating sources in the Central United States as a major problem for reduction of PM ambient concentrations in Ontario:

> *One should be cognizant of the fact that, without compatible U.S. emissions reductions, the effectiveness of Ontario's reduction efforts alone will be greatly compromised...*
>
> *(SOD p.4)*

These issues are further described in the SOD Section 5.1 under the source type "Transboundary Source Pollution", and various mitigation measures are briefly delineated. The Panel acknowledges that the selection of a strategic option for $PM_{10/2.5}$ by Ontario should not depend on corresponding regulatory initiatives in the United States. Nonetheless, the Panel strongly recommends that Ontario MOE should carefully consider the potential benefits of implementing a more stringent Ontario-specific or Canada-wide AAQC for $PM_{10/2.5}$, as setting a positive example for the U.S. federal or state jurisdictions in future harmonization talks.

The second issue is whether the CD provides sufficiently detailed modelling information regarding health benefits and cost of control, to allow evaluation of the criteria proposed within a specified option. Two Strategic Options -- Option 4 and Option 5 -- specifically address the question of different AAQC implementation in Air Quality Management Areas (AQMAs). There is a considerable amount of relevant and useful information provided in the CD describing the nature of this problem. The issue of community-specific emission controls, for example, is modelled analytically in CD Section III.5..4.2 "Avoided Health Impacts (Health Benefits) of Achieving Various Goals" (including Tables III.5.8 - III.5.11 p. III.5-38-43).

However, these model analyses are incomplete because they merely present estimates of the expected percentage of community-wide reductions in PM emissions corresponding to specified AAQC levels for PM_{10} and $PM_{2.5}$. While these emission reductions (expressed as percent reduction in the integrated existing $PM_{10/2.5}$ burden for a given locality) are assumed to be roughly proportional to the expected health benefits, no actual projection of reduced mortality and morbidity is presented in the CD. The major underlying difficulty here is that this type of community-specific analysis is not well suited to proportional linear rollback scenario used by the HB/AQVM model for estimating the cost-benefit of emissions reductions.

Any community-specific model would be extremely dependent on local air dispersion and population distribution factors, and these cannot be adequately addressed by the low-resolution data and models currently available. The CD, in fact, acknowledges that this approach requires more detailed source-receptor modelling that is not yet available (CD iv.8). This methodological problem appears to be partly addressed in Option 5, which proposes that implementation of a more rigourous AAQC standard for the AQMAs in Ontario should be based on a deferred implementation time line. The longer time frame for AQMAs offers some opportunity for conducting empirical evaluation studies for air quality monitoring tools and models. However, the Panel suggests that it is premature to consider either Options 4 or Option 5 as a viable Strategic Option until well-validated source receptor modelling is developed.

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2. Characterization of viable options

The remaining viable Strategic Options -- Option 1, Option 2, Option 3, and Option 6 -- must be characterized with respect to their implementation objectives, their declared decision criteria, and their dependence on scientific and cost-benefit information provided in the CD.

In the view of the Panel, each of the viable strategic options represents a prototype of the various distinctive approaches that could be employed to minimize the health risks associated of PM air pollution. These approaches are characterized in the option analysis according to the following scheme:

Option 1 - prudent avoidance approach

Option 2 - programmatic approach

Option 3 - incrementalist approach

Option 6 - biphasic approach

Each of the viable options has its own strengths and weaknesses. However, the main concern of the Panel was to consider how the gaps and uncertainties in the knowledge base provided in the CD impacts on the decision criteria described for each of the options (SOD Table 1).

OPTION 1

Option 1 has been viewed by the Panel as a 'prudent avoidance' approach to regulatory policy. Prudent avoidance is an common approach to risk reduction that is frequently used by regulators in situations where setting a revised standard for environment exposure is thought to be prudent, but where the exact nature and level of the standard is unclear due to large scientific uncertainties. Prudent avoidance is an action-oriented approach that attempts to achieve short-term technological solutions to mitigating health risks, such as reduced emissions of PM and PM-precursors, while seeking to avoid defining a revised AAQC standards until the state of scientific knowledge becomes more certain.

This option is apparently considered by MOE as the default option that would be selected if none of the alternative options proves viable or feasible, partly because its implementation is already underway in the setting of an interim AAQC at 50 ug/m^3 PM_{10} as *"...existing proposed* (sic) *MOE policy*". As an interim guideline, this AAQC has no powers of regulatory enforcement, but sets a benchmark for future consideration of AAQC levels in Ontario and in the Canada-wide standards process. The main advantages of this approach include maximizing flexibility for future emissions reduction programs and allowing more time for further scientific research to reduce current uncertainties. A major uncertainty here is that, while the 50 ug/m^3 PM_{10} interim AAQC can be supported by the cost-benefit analysis provided in the CD report, this cost-benefit assessment is incomplete due to inclusion of 1990 emissions data in the CD.

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This option has several ambiguities with respect to AAQC standards development and implementation, which obscures some of its objectives. Option 1 sets as one of its objectives a modest, (presumably low-cost) 10% reduction in PM emissions. However, the CD does not present a socio-economic model analysis of the costs or health benefits for a 10% emissions reduction scenario. Also, the socio-economic analysis in the CD assumes that Ontario's economy is static and that pollution burdens will not increase if the *status quo* is maintained. In many major air pollution issues this is not the case, as the baseline for emissions may change as the economy changes.

In addition, the stated target for emissions reduction under Option 1 appears to be arbitrary (10%) and is apparently unrelated to the emissions targets required under the interim AAQC. Specifically, the SOD p.1 states that: *"... attainment of the 50 ug/m^3 level will result in reductions of 34% of the total PM-related health impacts in Ontario"*. It is difficult to reconcile the absolute 10% reduction emissions target and the 34% reduction emissions target for the interim AAQC. This discrepancy appears to represent an implicit underlying assumption that 'other developments '(undefined) will somehow allow AAQC attainment with large emissions reductions. These might possibly include spin-off benefits from other smog reduction programs, such as reduced production of ozone and SO_x emissions (as PM precursor gases).

Finally, under Option 1 it is unclear whether the focus of the 10% target reduction in PM emissions is PM_{10} or $PM_{2.5}$. The full description of the option recommends that the focus should be: *"...reduction actions for emissions of primary fine particulate matter and precursor gases"*. This phrasing suggests that $PM_{2.5}$ is the principle target for emissions reductions, but it is unclear whether $PM_{2.5}$ and precursors are the primary target for emissions reductions, or merely subsumed under PM_{10}.

OPTION 2

Option 2 has been viewed by the Panel as a "programmatic" approach to regulatory policy. Programmatic approaches are commonly employed in environmental health policy-making when the residual scientific uncertainties are considered as relatively small and manageable. The main concern is then focussed on the technical feasibility and cost-effectiveness aspects of program implementation. Programmatic approaches such as Option 2 treat the problem of deriving appropriate AAQC levels under uncertainty as a difficult challenge, but not an insuperable obstacle. Hence, the specification of definite short-term and long-term AAQC values affirms the confidence of the policy-maker that such AAQC standards are both desirable and feasible.

The cost-benefit analyses presented in the CD are relatively well-suited to supporting this type of regulatory option, as the CD provides both projected health benefits and projected costs of controls within the HB/AQVM and AERCO$T™ models for AAQC levels set at 60, 50 or 40 ug/m^3 PM_{10}. However, the usefulness of these model predictions is largely vitiated by the lack of emissions reduction scenarios other than linear proportional rollback, by the exclusive adherence to a linear nonthreshold dose-response model, and by a questionable methodology for deriving the cost estimates for emissions controls based on incomplete data.

Option 2 does not provide absolute targets for PM emissions reductions. This allows for future flexibility in adhering to the revised AAQC standards according to the most cost-effective means of control. The approach advocated in Option 2 is basically goal-oriented rather than action-oriented, because the option does not specify any absolute emissions reduction targets for PM. This approach would allow the MOE to declare a set of target emissions reductions for PM, but these would likely be subsumed under the implementation plan for the revised AAQC ambient air standard.

The provision of prescribed interim and long-term AAQC target levels and dates permits decision-makers to balance off stringent AAQC levels with cost-effective emissions strategy. This is advantageous to industry stakeholders who prefer a definite set of emissions goals and time lines. However, under this option, current scientific uncertainty might be incorporated into the revised AAQC levels by including a large safety factor (uncertainty factor), which in turn produces a relatively stringent AAQC standard. Such an AAQC standard might be relatively costly and inflexible to implement by industry. However, the possibility of an extended time frame for implementation provides considerable flexibility in the selection of control technologies (which evolve rapidly) and strategies for regional airshed management (which is in its infancy).

A major potential pitfall to Option 2 is the inclusion of a definite AAQC for $PM_{2.5}$. The advantage of specifying a definite AAQC for $PM_{2.5}$ is to set the issue 'on the table" for further discussion and resolution. On the other hand, the uncertainties regarding $PM_{2.5}$ health effects and cost of control are so much greater than for PM_{10} that a programmatic approach might not be cost-effective. (see Option 6).

OPTION 3

Option 3 has been viewed by the Panel as a "incrementalist" approach to regulatory policy, which essentially adheres to the programmatic style advocated in Option 2, but defers the commitment to enforceable AAQC standard to an undefined future time line. In this sense, Option 3 may be regarded as a somewhat 'softer' version of Option 2, better reflecting the very large uncertainties inherent in the adoption of a specific AAQC level. The time dimension is treated as a flexible parameter to allow for the resolution of current uncertainties about health effects and costs of control.

Although Option 3 has very similar decision criteria to Option 2, the implementation objectives are more action-oriented rather than goal-oriented. By setting out firm short-term emissions targets and/or interim AAQC targets that require equivalent emissions reductions, Option 2 attempts to ensure that AAQC development and emissions reductions program proceed separately but in the same direction -- a "parallel path" approach to risk reduction. In this sense Option 3 is a hybrid on Option 1 and Option 2. It is not clear whether Option 3 specifically addresses both the PM_{10} vs. $PM_{2.5}$ AAQC issue, but it is assumed that the formulation of AAQC standards is similar to Option 2 which defines separate PM_{10} and $PM_{2.5}$ AAQC.

OPTION 6

Option 6 has been viewed by the Panel as a "biphasic" approach to regulatory policy, where PM_{10} and $PM_{2.5}$ are essentially treated as distinct components of air pollution to be regulated separately. Option 6 proposes to develop a firm AAQC standard for PM_{10} in the short-term, while the AAQC for $PM_{2.5}$ would be deferred to an undefined future date. The major advantage of this approach is that it allows the PM_{10} AAQC standard to be developed with minimal scientific and technological uncertainty, and allows time for further reduction in the larger uncertainties associated with $PM_{2.5}$.

There are also several important disadvantages to this biphasic approach. First, it is questionable whether PM_{10} is the most suitable particulate to be regulated on a priority basis. It is entirely uncertain whether PM_{10} acts as a direct toxicant, perhaps by eliciting harmful acute lung reactions in the large airways (Anderson, 1997), or instead whether PM_{10} serves merely as an unreliable surrogate for $PM_{2.5}$ toxicity.

This question is important to emissions control strategies because $PM_{2.5}$ reductions necessarily entail PM_{10} reductions, but PM_{10} reductions do not necessarily entail $PM_{2.5}$ reductions. It is intuitively attractive to reduce this type of uncertainty by adopting emission control strategies that focus principally on $PM_{2.5}$, notwithstanding the concern that $PM_{2.5}$ controls may be more costly than PM_{10} controls, and may therefore reduce overall cost-effectiveness.

Finally, considering that the proposed U.S. EPA NAAQS standard for $PM_{2.5}$ is now under judicial review, the best course of action may be to undertake a "watching brief" until the matter is resolved. Another attractive option is to regulate ambient $PM_{2.5}$ levels with a short-term AAQC, but to depend on gaseous precursor controls to reduce formation of secondary $PM_{2.5}$. For this strategy to be effective, much better regional and locality specific monitoring of $PM_{2.5}$ ambient concentrations is required. However, it must be recognized that $PM_{2.5}$ may in turn be a surrogate for other agents in PM_{10} that are harmful to health -- for example, sulphate particulate or ultrafine particulate (PM<1.0).

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Chapter 4

Recommended Research Directions for Particulate Matter

Chapters 1 and 2 have outlined a number of identified information gaps and uncertainties in the Compendium Document (CD). This section provides recommendations for a program of research to extend current understanding of particulate matter and its health effects, and to contribute to the development of effective public policy.

I. Classification of Research Needs

The Panel has identified the need for research in the following four major subject areas:

- assessment of the Ontario airshed, including chemical and physical characterization of particulate matter and understanding the links between PM or PM precursor emissions and ambient PM levels/exposure
- identification of potential health impact of IP/RP and the quantitative assessment of health risks,
- development of cost-benefit models for $PM_{10/2.5}$ control in Ontario, and
- evaluation of possible regulatory and non-regulatory interventions and initiatives.

Research needs of each of these four subject areas have been classified according to three types of investigation:

Mechanistic Studies: This research may focus on the more basic scientific information gaps such as dose- response relationships, biochemical mechanisms of actions, and secondary pollutant formation. These information needs are not unique to Ontario, but extend to all jurisdictions where inhalable particulates are a perceived health risk.

Monitoring Studies: This applied form of research focuses on the development of a database of ambient / RP measurements, as well as chemical emission profiles for polluting sources. The monitoring research component may also include a database of IP-related health effects (e.g. hospital admissions for asthma episodes) and their frequency of occurrence over a period of many days.

Modelling Studies: Research into the modelling of airshed systems, health impacts, and socio-economic systems is included in this form of study.

II. Specific Research Needs

The Panel recommends a program of research to address four major questions:

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1. Is the Ontario airshed assessment complete?

Chapter 1 has listed a number of information gaps related to measurements of inhalable particulate matter within Ontario. There is a considerable need for further monitoring and regional scale modelling in the development of provincial regulatory policies and local implementation plans. As a point of clarification, pollution *implementation plans* are not guidelines, but they are developed on the basis of what standards and guidelines must be attained, and they may specify how a local emission source should be curtailed to improve ambient air quality.

Monitoring Studies: There is a need for a broad database of PM_{10} and $PM_{2.5}$ measurements to be made across the province such that there is at least one full year of data representing the air quality of the majority of Ontario's populated areas. In addition, there is a need to identify and quantify major source emissions for primary particulates and for precurors of secondary particulates. The monitoring effort should include measurements of mass, size and chemical composition as well as of precursor species that are critical to the formation of secondary aerosols (e.g. sulphur oxides, nitrogen oxides, volatile organic compounds and ammonia). In addition, monitoring studies should be conducted to provide a data basis for accurately assessing the levels of particulates that originate "out-of-province" and that are of biogenic and natural background origins.

At this time, there is no perfect "metric" to relate ambient atmospheric particulates to human health. Current regulatory initiatives have used the measures of PM_{10}, and $PM_{2.5}$. In the past, the "PM_{10}" measure has received the most attention by most active regulators. However, the MOE needs to gather more information on $PM_{2.5}$ levels in Ontario, as this may be a more useful measure of respirable impact than PM_{10}. Since the actual mechanisms of PM caused health effects are not yet understood, detailed information about ambient particle composition, size and morphology are needed as a basis for health effect studies.

Modelling Studies: The MOE and Environment Canada possess considerable expertise in transboundary, regional, and local scale modelling. In particular there is a need for a clarification of the influences of air mass motions across North America on the displacement of particles and smog. One option is to conduct "back trajectory analyses" for a representative number of days that identify the long-range transport component of Ontario aerosol, and the component that originates in Ontario and moves on to Northern U.S. and Quebec. This should include the levels and identity of the secondary particulate precursors, primary particulate, and secondary aerosol formation.

The "representativeness" of single stations to cover regional populations such as Toronto, Hamilton, and others needs to be clearly defined. The local pollution gradients in a region become important to the evaluation of health effects. The variation in pollution levels around important urban representative sites should be assessed with the intention of understanding the short-term temporal and spatial changes that influence personal exposure. In addition, an individual is usually exposed to a combination of outdoor and indoor air situations. The impact of outdoor PM levels on indoor air quality should be studied in more detail.

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Mechanistic Studies: There is a continuing need to research the formation, accumulation, reactivity, and removal processes of particulate. Specifically the formation and loss processes for secondary particles, including the impact of biogenic precursors needs to be studied. Futhermore, the atmospheric mechanisms which relate emissions and ambient levels are at present only partly understood.

2. *Is there sufficient information to make good judgements about the health effects of IP and RP?*

It is clear from the CD review that there are significant uncertainties in the assessment of the links between IP/RP exposure and human health effects.

Mechanistic Studies: There is a need for a better understanding of the basic mechanisms of particle toxicity and the effects of different kinds of "particles" in the respiratory system. The key determinants of particle toxicity must be identified and their influence on morbidity/mortality estimated. The role of co-pollutants and the interactive effects of particles and gases would be important both to articulate more clearly the "particle"-adverse health outcomes relationship and guide targetting of exposure reduction strategies.

The large solubility component of $PM_{2.5}$, in particular, suggests that much of the particulate deposits in the respiratory system as a soluble salt. An understanding of the chemistry of the deposited particles and the co-pollutants is important. How does it react, absorb, or transfer through the lung membranes and how is a soluble aerosol cleared?

Monitoring Studies: A more effective ambient particulate monitoring network will contribute to future epidemiological studies. Better exposure data covering finer geographical divisions (e.g. more monitors covering different sections of Air Quality Management Areas - AQMA), and sampling over shorter time frames (e.g. hours versus weeks), with some chemical speciation and size fractionation will improve information coming from ecological time series population studies on particle-health relationships. At the same time, the measures of other co-pollutant exposures (e.g. CO, SO_2, NO_x, etc.) will contribute to the database needed to develop robust epidemiological studies. Recent work on co-pollutant relationships is being evaluated by other researchers. In addition, new co-pollutant studies are being developed. There will be confirming, supporting, and/or new evidence coming forward over the next year and this should help clarify this information gap.

The greater intensity and diversity of airborne particulate monitoring should also be mirrored in our sampling of health data indicators in targeted studies. Longitudinal cohort studies, for example, are extremely useful when applied in multiple AQMAs in which documentation of exacerbations and development of chronic disease can be linked. The inclusion of more sensitive health outcome data such as medication prescriptions and clinician visits across the range of human morbidity may also be added to the "monitoring" component.

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At the same time, some of the issues about "harvesting" vs. "life-shortening" need to be resolved as monitored individuals can be tracked over time within specific age groups categories. *Expected life expectancies* (and quality-of-life expectancies) can then be compared with *actual life expectancies* in individuals, and the "potential years of life lost" (PYLL) and "quality adjusted life years" (QALY) may be calculated. Research on valuation of health outcomes can be conducted on cohort members to improve the current limited assessments (by condition and by sub-population) and updated over time, given that these may change with changes in societal values, etc. Although such research would be expensive and require major long term commitments, it would keep Ontario and Canada in the forefront of air pollution health effects research over time.

Modelling Studies: There will continue to be debates about the modelling of "health effects thresholds" and the nature of the exposure-dose-response relationship until very sensitive epidemiologic studies are used to resolve the issue. Further attempts at different statistical modelling approaches to existing data are unlikely to clarify the specific dose-response relationships of interest. Currently, the application of the "lowest observed adverse effect levels (LOAEL)" are based on a broad population surveyed over an extended period of time.

The extent to which ambient exposures lead to specific health effects might be better modelled through simulation models and complex covariance models (e.g. structural equation modelling) to better express the less than direct linkages between the different steps. The data requirements of such work are substantial and may be achieved in longitudinal cohort studies of those with cardiorespiratory disease. In the interim, non-parametric approaches such as decile analyses (as used in Chapter 13 on reference levels in the SAD) in the range of observed ambient exposures (i.e. not extrapolating towards zero as per the CD) may be more appropriate.

3. What information is needed to improve the socio-economic analysis of proposed particulate reduction regulations?

Development and validation of a fully integrated risk-cost-benefit model for assessing the health risks, health benefits, and costs of control for reduced exposure to $PM_{10/2.5}$ is a pressing need for research in socio-economic analysis of PM control programs. The TAF model currently in development as part of the NAPAP research program in the United States may serve as a prototype of a fully integrated risk-cost-benefit model. In addition, the incorporation of probabilistic modelling techniques (e.g. Monte Carlo simulation; uncertainty analysis) into integrated models such as TAF demonstrates the need for development of similar modelling approaches in Canada.

There appears especially to be significant research needs associated with the development of robust Ontario-specific socio-economic models. There is a strong demand for research, for example, on the costs of implementing new technologies, and retrofitting older systems. A better understanding of the costs of health impacts below the "health reference level" is needed. The CD analysis assumes that all PM reductions will improve health, and calculate health benefits using a "no threshold" approach. This is acceptable for the analysis of concentrations that are above the reference level but there is inadequate

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information for those conditions that are below the level and when "low pollution" days are reduced even further. Is it a good assumption to use identical estimates of health benefits when air particulate levels are above or below the reference level?

Have predictions been made of Ontario's projected particulate emissions and ambient concentrations on the basis of current trends in technology, economy, population growth/decline, climate patterns/changes etc for the year 2020? In the 1990's any progress on vehicle emissions was overtaken by the increase in vehicles on the Ontario roads.

Although a guideline or standard may be set, the enforcement of the standard on an emission by emission basis is defined in the implementation plan. On the basis of the historical air quality data, it is apparent that many or most regions will meet guidelines of 50-60 ug/m^3. However, in some locations implementation plans (including industry emission reductions, certificates of approval changes, and point of impingement criteria) will be identified to meet the guidelines. Do we have adequate information to regulate individual AQMAs and how should important questions of equity between regions be balanced?

4. How do we gauge the effectiveness of the various interventions and strategies currently in place to manage air quality issues in Ontario?

There is a need to research the effectiveness of a number of different non-regulatory interventions and regulatory measures after they are deployed. The review process came across many cases where results are expected for various intervention methods, but we are unable to evaluate their impact on parallel processes. It has been proposed, for example, that significant reductions in IP will be accrued from parallel reductions in smog precursor gases; however, the modelling capability is not yet mature enough to quantify the overall effect with the needed accuracy. Education programs have raised the sensitivity of air pollution issues among the public of Ontario, and this may, among other things, affect their behaviour and practices when choosing between public and private vehicle transportation. Regulatory evaluation research is needed to track the effectiveness of other initiatives, such as:

- fuel changes (e.g. does sulphur reduction in fuel reduce ambient levels of sulphates in Ontario?),
- mobile site emission reduction programs (e.g. Drive Clean). Will this reduce the amount of IP/RP in the air and at what cost per tonne? Per citizen?,
- mobilization/education strategies (e.g. will the current OMA smog advisory health message program (Abelsohn et al. 1999) be any more effective than the federal one in terms of greater awareness and changed behaviour (Stieb et al. 1996)? Or can a multi-stakeholder community assessment, intervention, and monitoring program on air quality (such as the Hamilton Air Quality Initiative - HAQI) increase actions to improve air quality among the different stakeholders?

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- personal exposure reduction strategies either of behaviour change (e.g. does staying indoors really reduce particle exposure for vulnerable individuals?) or device utilization (e.g. does wearing a fine particle/charcoal mask during smog episodes reduce the severity of asthmatic episodes or extent of medication use?)

- shifting the responsibility and costing of regulatory initiatives (e.g. do different regulatory costing allocations result in better policies, such as emission credit trading or voluntary regulatory initiatives)

Each of these studies requires a different set of evaluation research methods and skills and this may be an important field of development as Ontario continues to experiment with different regulatory models.

III. Specific Ontario Needs

It is not possible to pursue all our perceived research needs due to time and cost concerns. Perhaps the best strategy is to pursue research that contributes to the development of good policy decisions within the Ontario IP Strategy. A short list emphasizes the strengthening of Ontario's modelling, monitoring, and exposure assessment capabilities as an IP/RP strategy is implemented. Other initiatives that investigate local airsheds, the sources and origins of Ontario particulate, and some targeted epidemiological studies (as noted previously) will contribute significantly to effective regulations. A list of proposed research directions is provided as follows:

1) Develop and maintain a network of PM_{10} and $PM_{2.5}$ samplers across the province with the capability to measure ambient levels of particulate in populated and natural background representative areas. The network should also provide the capability to make some assessment of the transboundary component particulate entering and leaving the provincial geographical region.

2) Conduct studies to obtain an overview of size, particle morphology, and chemical composition representative for Ontario.

3) Develop a modelling capability for the Ontario airshed. This should include estimates of the transboundary influences on the airshed during a number of typical meteorological systems. Focus studies (such as the Hamilton Air Quality Initiative) should be conducted on major population regions such as the Metropolitan Toronto region, Windsor, the Cambridge-Kitchener-Waterloo region, and Ottawa. Source apportionment methods need to be developed further to allow development of targeted and optimized emission reduction strategies.

4) Develop ambient air exposure profiles for average and non-average members of the public that will allow estimates of impact of poor air quality to be better understood.

5) Conduct further research into the production and loss of secondary particulate.

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6) Conduct a longitudinal epidemiological study within the province to contribute to the existing database on the influence of IP/RP on human health.

7) Conduct further research into the toxicity of IP/RP and the influence of co-pollutants as determinants of human health.

8) Further development of an economic model for estimating the costs associated with air quality improvement measures. This economic model should use an Ontario-specific economic baseline measure and allow the estimation of costs and benefits associated with a broad range of air pollution-related health outcomes.

9) Development of a broad risk-benefit model that can be employed for air quality regulatory efforts.

10) The development of a program for independent review of regulatory and non-regulatory initiatives within Ontario.

These recommendations are not prioritized. In addition, the Panel agreed that scoping of approximate costs and time frame for a research program were well beyond the scope of this assignment. This was noted in Appendix B.

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References

Abbey, D.E., B.L. Hwang, R.J. Burchette, T. Vancurren, P.K. Mills (1995). Estimated long-term ambient concentrations of PM_{10} and development of respiratory symptoms in a nonsmoking population. Arch Environ Health 50(2): 139-52.

Abelsohn A., J.E. Gray, T.E. Broadway (1999). OMA smog advisory health messages for physicians and patients. Ontario Medical Review. 66(5):19-23

Anderson, J.W. (1997, February). Revising the Air Quality Standards: A Briefing Paper on the Proposed National Air Quality Standards for Particulate Matter and Ozone. Washington, D.C. Resources for the Future.

Barnard, R.C. (1991). Major issues raised by the OMB report from the perspective of the regulator agencies. Regulatory Toxicology and Pharmacology. 14(3): 223-228.

Bartoszek, F.E., E.R. Vasquez,., W. He, and J.S. Chang (1998). Combustion Science and Tech. 133, 161-190.

Buckingham, K. (1993). A note on HYE (Health Years Equivalent), Journal of Health Economics, 12 (3), 301-310.

Burnett, R.T., S. Cakmak, M.E. Raizenne, D. Stieb, R. Vincent, D. Krewski, J.R. Brook, O. Philips, H. Ozkaynak (1998a). The association between ambient carbon monoxide levels and daily mortality in Toronto, Canada. J. Air & Waste Manage. Assoc. 48: 689-700.

Burnett, R.T. (1998b). Health effects of particulate and gaseous air pollution in Canada. Presentation to the IP/RP Options Assessment Working Group. Sept. 14, 1998. Toronto.

Burtraw, D., A. Krupnick, E. Mansur, D. Austin and D. Farrell (1998). Costs and benefits of reducing air pollutants related to acid rain, Contemporary Economic Policy, XVI, 379-400.

Cahill, T.A., P.J. Feeney, and R.A. Eldar (1987). Nucl. Instr. Meth., B.22, 344-348.

CASAC (1995). Clean Air Scientific Advisory Committee (CASAC) Comments on the April 1995 draft Air Quality Criteria for Particulate Matter. EPA-SAB-CASAC-LTR-95-005. August 31, 1995. U.S. EPA.

CASAC (1996a). Clean Air Scientific Advisory Committee (CASAC) Comments on the November 1995 Drafts of the Air Quality Criteria for Particulate Matter and the Review of the National Ambient Air Quality Standards for Particulate Matter: Policy Assessment of Scientific and Technical Information (OAQPS Staff Paper), EPA-SAB-CASAC-LTR-96-003. January 5, 1996. U.S. EPA.

CASAC (1996b). Closure by the Clean Air Scientific Advisory Committee (CASAC) on the Staff Paper for Particulate Matter. EPA-SAB-CASAC-LTR-96-008. June 13, 1996. U.S. EPA.

CEPA/FPAC (1997). Working Group on Air Quality Objectives and Guidelines. National Ambient Air Quality Objectives for Particulate Matter. Part 1: Science Assessment Document. Consultation Draft.

©CRESTech 1999

Commonwealth of Australia (1993). National Health Survey, Issues paper No. 7, March.

Dockery, D. W., C.A. Pope, X. Xu, J.D. Spengler, J.H. Ware, M.E. Fay, B.G. Ferris, F.E. Speizer (1993). An association between air pollution and mortality in six U.S. cities . N Engl J Med 329(24): 1753-9.

Energy Research Laboratory (1991) Technical Report on Next Generation De-SO_x and De-NO_x Technology, Report No. 2EP-18. MITI, Japan.

Finkel, A. (1990). Confronting Uncertainty in Risk Management: A Guide for Decision-Makers. Center for Risk Management, Resources for the Future, Washington DC.

Frey, H.C. and E.S. Rubin (1991). Probabilistic Evaluation of Advanced SO_2/NO_x Control Technology, Journal of the Air and Waste Management Association, 41(12):1585-1593.

Fuchs, V. R. and R. J. Zeckhauser (1987). Valuing health - a priceless commodity, American Economic Review, 77, 263-268.

Hagler Bailly (1996). Air Quality Valuation Model (AQVM) Report 2: Methodology. Draft Final Report prepared for Environment Canada and Health Canada. Hagler Bailly Consulting Inc. Boulder, Colorado. June 17, 1996.

Henriques, I. and P. Sadorsky (1999). The relationship between environmental commitment and managerial perceptions of stakeholder importance, Academy of Management Journal, 42 (1), 87-99.

Henriques, I. and P. Sadorsky (1996). The determinants of an environmentally responsive firm: An empirical approach, Journal of Environmental Economics and Management, 30 (3), 381-395.

Hicks, J., and J. Pritchard (1986). Experimental evaluation of aerosol growth in the human respiratory tract. In Aerosols, Formation and Reactivity, 2nd International Aerosol Conference, Berlin, FRG, Pergamon Press, Oxford, U.K.

Hjalmarsson, A.K. and H.N. Sound (1992). Nitrogen Oxides Fact Book, Noyes Data Co., NJ, pp.149-361.

Johannesson, M. and P.O. Johansson (1996). To be, or not to be, that is the question: An empirical study of the WTP for an increased life expectancy at an advanced age, Journal of Risk and Uncertainty, 13, 163-174.

Johannesson, M. and P.O. Johansson (1997). Is the valuation of a QALY gained independent of age?: Some empirical evidence, Journal of Health Economics, 16 (5), 589-599.

Jones-Lee, M.W., M. Hammerton and P.R. Phillips (1985). The value of safety: Results of a national sample survey, The Economic Journal, 95, 49-72.

Kasahara, M., K. Takahashi, G.P.Reischl, and O. Preining (1992) J. Aerosol Sci.,23:S695-S698.
Lee, R., .A. Krupnick, D. Burtraw, D. et al. (1995). Estimating Externalities of Electric Fuel Gases: Analytical Methods and Issues and Estimating Externalities of Coal Fuel Cycles. McGraw-Hill Utility Data. Institute. Washington, DC.

©CRESTech 1999

Lowless, P.A., T. Yamamoto and Y. Otani (1995). Modelling of Electrostatic Precipitators and Filters. In Handbook of Electrostatic Processes, (Eds.) J.S. Chang, A.J. Kelly and J.M. Crowley Marcel Dekker Inc, New York, pp.481-508.

Masuda, S., and S. Hosokawa (1995). Electrostatic Precipitation. In Handbook of Electrostatic Processes, (Eds.) J.S. Chang, A.J. Kelly and J.M. Crowley, Marcel Dekker Inc, New York, pp.441-480.

Mitchell, B. (Ed.) (1995). Resource and environmental management in Canada: Addressing conflict and uncertainty. Oxford University Press, Toronto, Ont.

National Research Council, Committee on Research Priorities for Airborne Particulate Matter. (1998). Research Priorities for Airborne Particulate Matter: I. Immediate Priorities and Long-Range Research Portfolio. National Academy Press, Washington, DC.

Ontario Ministry of Environment (1999). Air Quality in Ontario 1996. A Concise Report on the State of Air Quality in the Province of Ontario (www.ene.gov.on.ca).

Ostro, B. and L. Chestnut (1998). Assessing the health benefits of reducing particulate matter air pollution in the United States, Environmental Research, Section A, 76, 94-106.

Pope, C. A., 3rd, M. J. Thun, M.M. Namboodiri, D.W. Dockery, J.S. Evans, F.E. Speizer, C.W. Heath (1995). Particulate air pollution as a predictor of mortality in a prospective study of U.S. adults. Am J Respir Crit Care Med 151(3 Pt 1): 669-74.

Porter, M. and C. van der Linde (1995). Toward a new conception of the environment-competitiveness relationship", Journal of Economic Perspectives, 9 (4), 97-118.

Porter, R. C. (1982). The New Approach to Wilderness Preservation through Benefit-Cost Analysis, Journal of Environmental Economics and Management, 9, 59-80.

Pratt, J.W. and R.J. Zeckhauser (1996). Willingness to pay and the distribution of risk and wealth, Journal of Political Economy, 104(4), 747-763.

Ried, W. (1998). QALYs versus HYEs - What's right and what's wrong: A review of the controversy, Journal of Health Economics, 17(5), 607-625.

Ruddy, E.N. and L.A.Caroll (1993). Chemical Eng. Progress, 89:28-35.

Samet, J., S. Zeger, J. Kelsall, J. Xu and L. Kalkstein (1998a). Does weather confound or modify the association of particulate air pollution with mortality? An analysis of the Philadelphia data, 1973- 1980. Environ Res 77(1): 9-19.

Samet, J. M., S. L. Zeger, J.E. Kelsall and X. Jing. (1998b). "Particulate air pollution and mortality: The particle epidemiology evaluation project." Applied Occupational and Environmental Hygiene 13(6): 364-369.

Schelling, T. C. (1973). The value of preventing death. In Cooper and Culyer (eds), Health Economics, Hammondsworth, U.K.: Pengum Books.

©CRESTech 1999

Schmidheiny, S. (1992), Changing Course: A Global Business Perspective on Development and the Environment. MIT Press, Cambridge, Mass.

Schwartz, J., D. W. Dockery, and L.M. Neas. (1996). Is daily mortality associated specifically with fine particles? J. Air Waste Manage. Assoc. 46: 927-939.

Schwartz J., G. Norris, T. Larson, L. Sheppard, C. Claiborne, and J. Koenig (1999). Episodes of High Coarse Particle Concentrations Are Not Associated with Increased Mortality. Environmental Health Perspectives 107(5): 339-342.

SENES Consultants Limited. (1996). User's Guide for Cantec. Report Prepared for Environment Canada.

SENES Consultants Limited. (1995). Canadian Control Technology Costing Study for NO_x, VOCs and SO_2. Report Prepared for Environment Canada.

SENES Consultants Limited. (1992). Proprietary information obtained from Environment Canada.

Stieb D.M., J. Paola, and K. Newman (1996). Do smog advisories work? Results of an evaluation of the Canadian Smog Advisory Program. Can J Public Health 87(3):166-169

Spark, L.E. and N. Planks (1989). U.S. Patent 4, 885,139.

Tanaka, M., K. Shimizu, K. Deshimaru, and S. Watari (1992). Nippon Steel Tech.Rept.55: 67-71.

U.S. EPA. (1996). Review of the National Ambient Air Quality Standards for PM: Policy Assessment of Scientific and Technical Information. Office of Air Quality Planning and Standards Staff Paper. EPA-452\R-96-013.

U.S. Federal Register (1997). National Ambient Air Quality Standards for PM. 62 Fed. Reg. 38, 652.

U.S. Court of Appeals (1999, May 14). District of Columbia Circuit. American Trucking Association Inc. et al. vs. EPA.

VanderZwaag, D. (1994). CEPA and the Precautionary Principle/Approach. Environment Canada, Reviewing the CEPA: The Issues # 18.

Vercammen, K.L., A.A. Berezin, F. Loxand J.S. Chang (1997). J. Adv. Oxidation Tech., 2: 312-329.

Wynne, B. (1992). Uncertainty and Environmental Learning: Reconceiving Science and Policy in the Preventive Paradigm. Global Environmental Change 1: 111.

Zeger, S. L., F. Dominici and J. Samet (1999). Harvesting-resistant estimates of air pollution effects on mortality. Epidemiology 10(2): 171-5.

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APPENDIX A

Appendix A may be found on pages 7 - 9 in the MOE document entitled: *"Strategic Options to Address the Fine Particulate Issue in Ontario".*

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TABLE 1: POSSIBLE IP/RP STRATEGIC OPTIONS AND ASSOCIATED CONSIDERATIONS

Strategic Options	Full Description	Considerations
1.Interim AAQC of 50 µg/m3 with at least 10% reduction in emissions	Affirm Ontario's interim ambient air quality criterion for PM_{10} of 50 $\mu g/m^3$ and the interim reduction target of at least 10% emissions contributing to IP/RP. Not to adopt a new long-term AAQC until adequate supporting information is available. In the meantime, focus on reduction actions for emissions of primary fine particulate matter and precursor gases.	- firm commitment to improvement of air quality and reduction of human health effects - provides stimuli to technological innovations - it is an existing proposed Ministry of the Environment policy - allows time for the science to develop - reduction in emissions points in the right direction - proposed reduction also contributes to improvements in other atmospheric issues - provides a reasonably long term target date, which allows IP/RP related emitter to build reduction requirements into their planning cycle - proposed AAQC is the same as those in other jurisdictions (e.g., British Columbia, Newfoundland, and California) but more stringent than corresponding U.S. standards - choice is based on incomplete benefit-cost assessment
2.AAQC with interim and long term target levels/dates	Develop 24-hour ambient air quality criteria (AAQC) for PM_{10} and $PM_{2.5}$ with fixed levels (e.g., 40 and 20 $\mu g/m^3$) and target dates (e.g., 2015), with the option of phased-in targets (e.g.,60 and 30 $\mu g/m^3$ for 2005 and 50 and 25 $\mu g/m^3$ for 2010).	- easier to track progress and more accountability - allows time for corrective actions if improvements are not realized - allows time for additional data collection and assessment to firm up the date to attain long term AAQC values - improvement of air quality and reduction of health incidents can occur while research into the development of a comprehensive strategy continues - more in line with the U.S. process, which in the near term has a focus on monitoring and assessment activities - short term (phased-in) targets lead to quicker actions, but may hamper flexibility in the choice of options and thus reduce overall cost effectiveness - fails to lay out emission reductions

Strategic Options	Full Description	Considerations
3.Long term AAQC and interim target levels or reduction percentages	Endorse long-term ambient air quality criteria (e.g., 40 and 20 $\mu g/m^3$ for PM_{10} and $PM_{2.5}$) without committing to a date and set interim targets based on ambient levels or % reduction	- easier to track progress and more accountability - allows time for corrective actions if improvements are not realized - allows time for additional data collection and assessment to firm up date to attain long term AAQC values - improvement of air quality and reduction of health incidents can occur while research into the development of a comprehensive strategy continues - more in line with the U.S. process, which in the near term has a focus on monitoring and assessment activities - long term targets are not favoured by the general public - short term (phased-in) targets lead to quicker actions, but may hamper flexibility in the choice of options and thus reduce overall cost effectiveness
4.Different AAQCs for AQMAs	Develop different ambient air quality criteria for areas that may be designated as IP/RP air Quality Management areas (AQMAS) and the rest of the province (e.g., 50 and 25 $\mu g/m^3$ for PM_{10} and $PM_{2.5}$ for designated areas, and 40 and 20 $\mu g/m^3$ for PM_{10} and $PM_{2.5}$ for the rest of the province).	- allows for flexibility in AAQC implementation - allows for the setting of more stringent AAQC for cleaner areas of the province - avoids having to set the AAQC based on the worst area - allows smaller/unique problem regions to meet the AAQC - inequity in protecting the health of people in Ontario - leads to delay in actions or no actions in problem areas
5.Different implement dates for AQMAs (same AAQC across Ontario)	Develop the same ambient air quality criteria across Ontario but some areas may be designated as IP/RP air quality management areas (AQMAS) with different implementation dates for achieving the PM_{10} and $PM_{2.5}$ AAQC, e.g., 2015 and 2020, respectively.	- allows flexibility in meeting the AAQC for problem areas - provide equal protection for all Ontarions in the long term - allows all communities to meet the same AAQC - parts of Ontario will be exposed to higher pollution levels in the short term - leads to delay in actions in some problem areas
6.AAQC for PM_{10} with $PM_{2.5}$ to follow	Develop ambient air quality criteria (AAQC) for PM_{10} for the time being. Postpone development of $PM_{2.5}$ AAQC until more information becomes available.	- allows time for the science and knowledge of $PM_{2.5}$ to develop - ensures reduction measures are based on better science - fails to address the most important issue since $PM_{2.5}$ is considered to be more important then PM_{10}
7.USEPA Standards for PM_{10} and $PM_{2.5}$	Adopt the USEPA standards for PM_{10} and $PM_{2.5}$	- harmonizes with the US - ensures level playing field for Canadian industries - does not place Canadian industries in an unfair disadvantage - viewed as a do-nothing scenario since most areas of Ontario already meet the US standards - inconsistent with Ontario interim and other provinces' PM_{10} AAQC - Ontario air quality could actually deteriorate

AAQC - ambient air quality criterion (24 hour average); AQMAs - Air Quality Management Areas

APPENDIX B

CRESTech

Memo

Date May 6, 1999
To: The PM and Ozone Options Assessment Working Group
of the Ontario Smog Plan Steering Committee
From: The Expert Review Panel

As you know from your participation on the PM and Ozone Options Assessment Working Group PM & O3 OAWG), two documents have been prepared for the Ontario Smog Plan Steering Committee by the Ministry of Environment:

1) A COMPENDIUM OF CURRENT KNOWLEDGE ON FINE PARTICULATE MATTER IN ONTARIO

2) STRATEGIC OPTIONS TO ADDRESS THE FINE PARTICULATE ISSUE IN ONTARIO.

The final draft of these documents will provide a compilation of available technical information and will be a resource for use in public consultation in the development of an Ontario IP/RP Strategy.

Through the Smog Plan Steering Committee and the PM & O3 OAWG, the MOE has engaged industry, non-governmental organizations (NGOs), and other levels of government in a stakeholder participation process focused on PM. The process has moved on to a scientific review stage that requires the current documented information be reviewed by an independent panel of experts. We have attached a list of the members of the panel and the objectives of their assignment. The panelists were selected from academia using the guidelines established by the Royal Society of Canada.

The Expert Review Panel met with the PM&O3 OA Working Group on April 20th, 1999 to discuss the terms of reference and the details of the scoping study. We have observed that some members of the PM & O3 OAWG were not at the public meeting. Please note that minutes of this meeting are available upon request.

We value your input and request that you inform the panel early in the process of any concerns that your organization may have with the expert review process, or if there is any additional information you believe is important for our panel deliberations. We request that if you have any comments, you contact the panel chair by May 17th 1999.

Sincerely,

Dr. Dan McGillivray
Unit Director,
Technical Secretariat .....
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Dr. John Hicks
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Attach. – Detailed objectives of the Scoping Study and List of Panelists

Attachment to May 6th, 1999 Memo

CRESTech / NERAM
Scoping Study on Information Gaps and Uncertainties in the IP/RP Compendium Documents and their Impact on Strategic Options.

Scoping Study Objectives:

1. to conduct a review of the IP/RP Compendium document and the Strategic Options document;
2. to identify the information gaps;
3. to determined the level of uncertainty associated with the information gaps;
4. to assess the impact of the information gaps/uncertainty on the seven strategic options (describing, where possible, brackets of uncertainty around the options);
5. to outline the path forward by defining a research program to close/bridge the gaps and reduce the uncertainties related to the seven strategic options presented in the document.

Expert Review Panel:

Dr. John Hicks, Chair, Ryerson Polytechnic University
Dr. Jen-Shih Chang, McMaster University
Dr. Irene Henriques, York University
Dr. Jochen Rudolph, York University
Dr. Donald Cole, McMaster University

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